DE-NOISING OF AN EXPERIMENTAL ACOUSTIC EMISSIONS (AE) DATA USING ONE DIMENSIONAL (1-D) WAVELET PACKET ANALYSIS

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with "specialization".

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Name of Supervisor:
Position:
Date:

Signature:
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Position:
Date:

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Wavelet transformation technique was founded to be more appropriate to analyse the AE signals under such situations. Wavelet transformation technique is used to de-noise the Acoustic Emission data. The de-noised signal is classified to identify a signature based on the type of phenomena. Through various filtering/thresholding techniques, it was found that the original signal was getting filtered out along with noise. There are many type of wavelet that can be used for de-noising data. However, daubechies wavelet is the most wavelet type is use in signal analysis compare to the other wavelet. A signal can be generates using one-dimensional wavelet packet analysis contain in MATLAB to verify the result of de-noising signal

ABSTRAK

Teknik Wavelet Transform (WT) merupakan suatu teknik yang sesuai diguna pakai untuk menganalisis isyarat Acoustic Emission (AE). Isyarat yang sudah di tapis dapt menentukan jenis fenomena yang berlaku. Melalui pelbagai teknik penapisan, didapati bahawa isyarat asal dibuang bersama-sama bunyi asing. Terdapat banyak jenis wavelet yang boleh digunakan untuk membuang bunyi asing dari isyarat asal. Bagaimanapun, daubechies wavelet merupakan jenis wavelet yang biasa digunakan berbanding dengan wavelet-wavelet yang lain. Isyarat boleh di hasilkan menggunakan perissian one-dimensional wavelet packet analysis yang terkandung dalam MATLAB untuk megenalpasti isyarat yang ditapis.

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LIST OF ABBREVIATIONS

1-D	One Dimensional
AE	Acoustic Emission
AET	Acoustic Emission Technique
CWT	Continues Wavelet Transformation
db	Daubechies
DWT	Discrete Wavelet Transformation
FFT	Fast Fourier Transform
NDT	Non-destructive Testing
RMS	Root Mean Square
STFT	Short-Time Fourier Transform
WFT	Windows Fourier Transform
WPA	Wavelet Packet Analysis
WT	Wavelet Transform

CHAPTER 1

INTRODUCTION

1.1 Introduction

The acoustic emission (AE) technique plays more and more important role in non-destructive technique (NDT) field, especially in material researching, pressure vessel evaluating and intensity watching and measuring for the component of plane. However the research for signal processing technique in AE detection is still a key problem in theory research and engineering application of AE detection technique. So it is necessary for us starting from software to find new method for AE signal processing, especially to seek a new digital signal processing way for noise removing. Wavelet analysis is a significant branch of applied mathematics, which has developed in recent years. It is called mathematical microscope, for it can be applied to remove noise from signal, coding and encoding, edge detection, data compress, mode identification and so on. Wavelet analysis has been used in signal processing more and more widely, and it had been used for removing noise from signal in seismic data (Grossman,1984).

Wavelets have been widely used in signal and image processing for the past 20 years. Although a milestone paper by Grossmann and Morlet (Grossman and Morlet, 1984) was considered as the beginning point of modern wavelet analysis, similar ideas and theoretical bases can be found back in early 20th century (Haar, 1910). Ever since, wavelet transforms have been successfully applied to many topics including tomographic reconstruction, image compression, noised reduction, image enhancement, texture analysis/segmentation and multi-scale registration.

While carrying out the AE testing, it is often found that the background noise is very high. To identify the original signal, it is necessary to understand the types of noise sources and to ensure the elimination of their influence (Weaver,1991). Different types of noise encountered during AE testing are mechanical noise, hydraulic noise, electrical (electromagnetic) noise, cyclic noise, welding noise, pseudo noise, etc.

Wavelet transformation technique is found to be more appropriate to analyse the AE signals under such situations. Wavelet transformation technique is used to de-noise the AE data. The de-noised signal is classified to identify a signature based on the type of phenomena. Due to the presence of these noises, it becomes difficult to make the right interpretation of the AE signature. To analyse the AE signal, it is essential to eliminate or reduce the noise. The noise can be reduced using filters, or by decreasing the gain and/or increasing the threshold. But this may affect the AE data, i.e., some of the low-amplitude AE signals may not be detected and also some of the. Though various signal processing tools like Fast Fourier Transform and Windowed Fourier Transform are available for analysis of these signals, it is found that the wavelet transform (WT) is more appropriate. In this paper, wavelet transform technique is used to de-noise the transient AE data. Further, the de-noised signal is classified based on the type of event or fault present in the original AE signal from the noise-influenced data (S.V.Subba Rao and B. Subramanyam, 2008).

1.2 Problem Statement

One Dimensional (1-D) wavelet packet need to be used to analyse the result of the acoustic emission data taken from M.H.Zohari,2008 experiment about the determination of internal pipe roughness. After all the data were de-noised and been analyse for the best level for de-noise signals need to determine by using selected daubechies

1.3 Objectives of The Project

- To determine the best daubechies wavelet for de-noising using 1-D wavelet packet analysis and entropy criterion of Shannon.
- To differentiate the acoustic emission data before and after de-noising using 1-D wavelet packet analysis

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter will briefly explain about the acoustic emission (AE) technique and it signal parameter, the comparison between wave and wavelet, type of wavelet, wavelet transform, wavelet packet and wavelet theory. All this information are important to complete this thesis.

2.2 Acoustic Emission (AE)

Acoustic emission as a non-destructive testing technique had its beginning in 1950 with the work of Joseph Kaiser. Between 1950 and 1960 the fundamentals of acoustic emissions, development of instrumentation for acoustic emission (AE), and and the characteristic of AE behavior of materials were mainly carried out in this era. The unique capability of AE as a non-destructive testing technique were begin to be appreciate also in this era. In the 1980s advanced signal processing was introduced to the data analysis of AE signal and presently a shift has occurred on AE activities emphasis been place on application than on research (Drouillard T.F,1996)

2.2.1 Acoustic Emission Technique

AE is defined as the class of phenomenon whereby transient elastic waves are generated by rapid release of energy from localized sources in a material. The AE occurs as a series of short impulsive packets of energy. The energy thus released from the packet travels as spherical wavefront and can be picked up from the surface of materials using highly sensitive transducers. The wave thus picked up by the transducer is converted into an electrical signal, which on suitable processing and analysis can reveal valuable information about the source (V.Ogbonnah,2007).

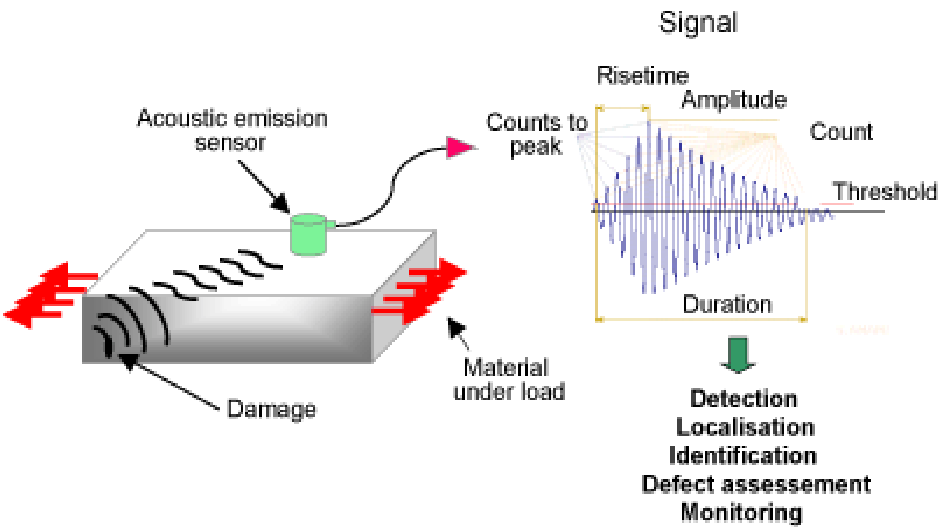


Figure 2.1: Acoustic Emission Testing

(Source: www.twi.co.uk)

While carrying out the AE testing, it is often found that the background noise is very high. To identify the original signal, it is necessary to understand the types of noise sources and to ensure the elimination of their influence. Different types of noise encountered during AE testing are mechanical noise, hydraulic noise, electrical (electromagnetic) noise, cyclic noise, welding noise, pseudo noise, etc. Due to the presence of these noises, it becomes difficult to make the right interpretation of the AE signature. To analyse the AE signal, it is essential to eliminate or reduce the noise. The noise can be reduced using filters, or by decreasing the gain and/or increasing the threshold. But this may affect the AE data, some of the low-amplitude AE signals may not be detected and also some of the AE signals may get filtered out with frequency components in the same range as that of noise (Mallat, 1992a).

Though various signal processing tools like Fast Fourier Transform (FFT) and Windowed Fourier Transform (WFT) are available for analysis of these signals, it is found that the wavelet transform (WT) is more appropriate. In this paper, wavelet transform technique is used to de-noise the transient AE waves. Further, the de-noised signal is classified based on the type of event or fault present in the original AE signal from the noise-influenced data. The results are found to be satisfactory (Unser,1996).

2.2.2 Acoustic Emission signal Parameters

Various parameters used in AET include: AE burst, threshold, ring down count, cumulative counts, event duration, peak amplitude, rise time, energy and rms voltage etc. Typical AE system consists of signal detection, amplification & enhancement, data acquisition, processing and analysis units. Figure 15 show the example of Acoustic Emission signal.

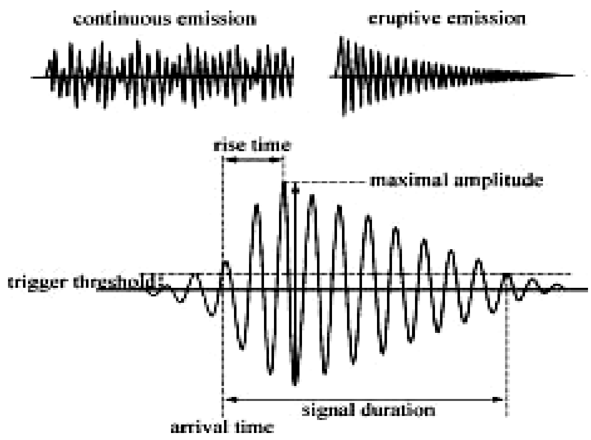


Figure 2.2: AE signal Parameters

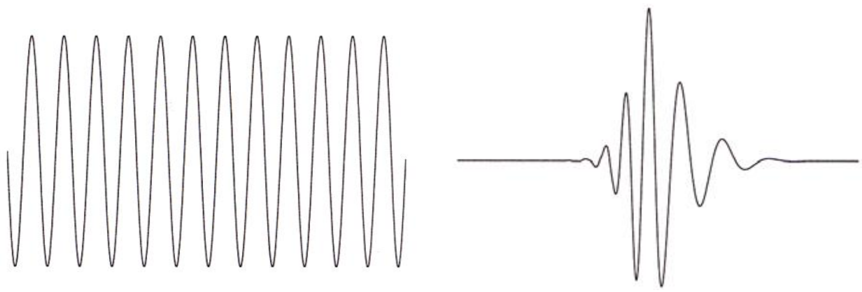
(Source: http://fib.bme.hu)

Different Acoustic Emission parameters were use for every different research. The AE parameter used depending on the researchers in finding the correlation between AE parameters to the analysed variables. The parameters used give different expression and meaning. Example for the RMS amplitude represent the energy of the signal and frequency show how fast the acoustic emission activity.

2.3 Wavelet

A wave is an oscillating function of time or space and is periodic. In contrast, wavelets are localized waves. They have their energy concentrated in time or space and are suited to analysis of transient signals. While Fourier Transform and Short-Time Fourier Transform (STFT) use waves to analyze signals, the Wavelet Transform uses wavelets of finite energy.

The Wavelet Transform, at high frequencies, gives good time resolution and poor frequency resolution, while at low frequencies, the Wavelet Transform gives good frequency resolution and poor time resolution



(a) (b)

Figure 2.3: Demonstration of (a) a Wave and (b) a Wavelet

Wavelet theory demonstrates that Lipschitz regularity of signal can be calculated its multi-scale behaviors of wavelet transform on modulus maxima figures. When we process signal using wavelet transform, because of the different Lipschitz regularity of signal and random noise, the change rules of the extremum point are different along with the change of scales. So according to this we can remove the extremum point corresponding to noise and then reconstruct signal. Thus purpose of denoising is achieved (S.V.Subba Rao and B. Subramanyam, 2008).

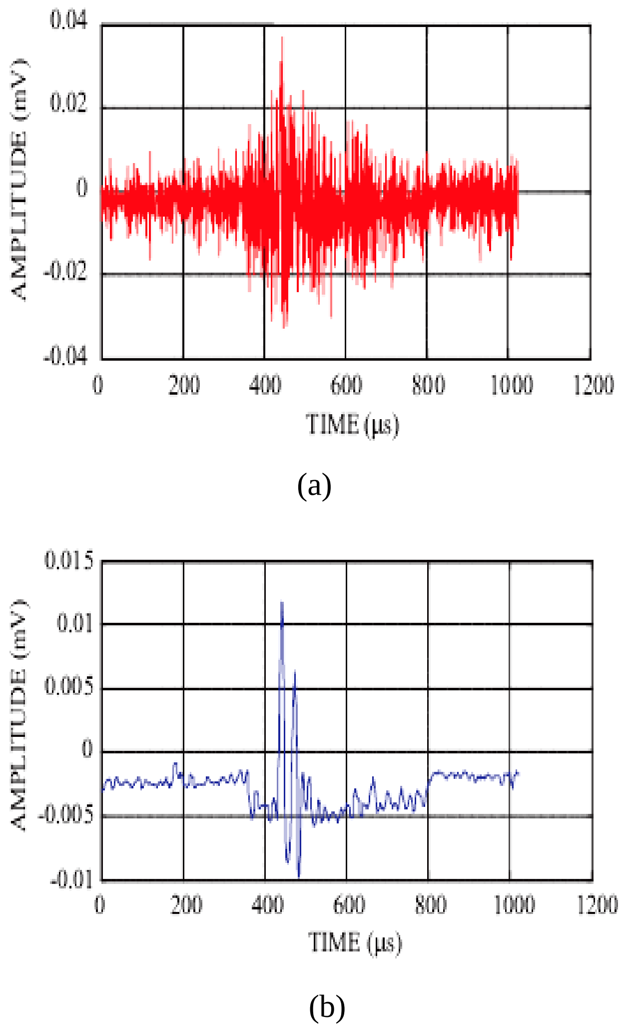


Figure 2.4: (a) Test-3 data and (b) de-noised data showing signal from rubbing of fasteners.

(Source: S.V. Subba Rao and B. Subramanyam,2008)

2.4 Wavelet Transform

Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. These basis functions are short waves of limited duration that have an average value of zero, which are scaled which related to frequency, thus the name wavelets is used.

In general, the wavelet y(t) is a complex valued function. A general wavelet function is defined as an equation below:

$$\Psi_{s,t}\ (t) = |s|^{\frac{1}{2}}\ \psi\left[\left(\frac{t-\tau}{s}\right)\right] \tag{1}$$

This shift parameter *t*, determines the position of the window in time and thus defines which part of the signal *x(t)* is being analysed. In wavelet transform analysis, frequency variable w is replaced by scale variable s and time shift variable t_1 is replaced by *t*. The wavelet transform localize these wavelet functions, and performs the decomposition of the signal *x(t)* into weighted set of scaled wavelet functions *y(t)*. The main advantage of using wavelets is that they are localized in space (Mallat.1998).

The most important properties of wavelets are the admissibility and the regularity conditions and these are the properties, which gave wavelets their names. It can be shown that square integral functions *y(t)* satisfying the admissibility condition, can be used to first analyse and then reconstruct a signal without loss of information. Fourier transform has a serious drawback, that is losing time information after transforming to frequency domain. But wavelet is small wave. This small means that a wave is localized in time domain, so its energy is finite. This localized property makes possible to allow time domain analysis of given signals without loss of information. Two types of wavelet transformation techniques, discrete wavelet transformation technique (DWT) and continuous wavelet transformation (CWT) technique are being used for signal analysis.

2.5 Shannon Wavelet Theory

Wavelets are localized functions which are a very useful tool in many different applications: signal analysis, data compression and operator analysis. The main feature of wavelets is their natural splitting of objects into different scale components according to the multi-scale resolution analysis. Shannon sampling theorem plays a fundamental role in signal analysis and, in particular, for the reconstruction of a signal from a digital sampling (C.Catanni,2005).. Under suitable hypotheses (on a given signal function) a few sets of values (samples) and a preliminary chosen basis (made by the sinc function) enable us to completely reconstruct the continuous signal. This reconstruction is alike the reconstruction of a function as a series expansion (such as polynomial, Taylor series, or trigonometric functions, Fourier series), but for the first time the reconstruction (in the sampling theorem) makes use of the sinc function, that is a localized function with decay to zero. Together with the Shannon sampling theorem (and reconstruction), also the wavelets series become very popular, as well as the bases with compact support. It has been recognized that on the sinc functions one can settle the family of Shannon wavelets (C. Cattani and J. Rushchitsky,2007).

2.5.1 Shannon Wavelet

Sinc function or Shannon scaling function is the starting point for the definition of the Shannon wavelet family (C.Cattani,2006). It can be shown that the Shannon wavelets coincide with the real part of the harmonic wavelets, which are the band-limited complex functions

$$\psi_k^n(x) \overset{def}{\equiv} 2^{n/2} \frac{e^{4\pi i(2^n x-k)} - e^{2\pi i(2^n x-k)}}{2\pi i(2^n x-k)} \qquad (2.1)$$

with *n, k* ∈ *Z*. Harmonic wavelets form an orthonormal basis and give rise to a multi-resolution analysis. In the frequency domain, they are very well localized and defined on compact support intervals, but they have a very slow decay in the space variable. However, in dealing with real problems it is more expedient to make use of real basis. By focusing on the real part of the harmonic family, we can take advantage of the basic properties of harmonic wavelets together with a more direct physical interpretation of the basis (C.Cattani,2006).

Let us take, as scaling function ψ *(x)*, the sinc function (see Figure 2.5)

$$\varphi(x) = sinc\ x \overset{def}{=} \frac{\sin \pi x}{\pi x} = \frac{e^{\pi i x} - e^{-\pi i x}}{2\pi i x} \qquad (2.2)$$

and for the dilated and translated instances

$$\varphi_k^n(x) = 2^{\frac{n}{2}}\varphi(2^n x - k) = 2^{n/2}\frac{sin\pi(2^n x - k)}{\pi(2^n x - k)} \qquad (2.3)$$

$$= 2^{n/2}\frac{e^{\pi i(2^n x - k)} - e^{-\pi i(2^n x - k)}}{2\pi i(2^n x - k)} \qquad (2.4)$$

The parameters *n, k* give, respectively, a compression (dilation) of the basic function and a translation along the *x*-axis. The family of translated instances { φ ($x - k$)} is an orthonormal basis for the banded frequency functions (Shannon theorem). For this reason, they can be used to define the Shannon multi-resolution analysis as follows.

The scaling functions do not represent a basis, in a functional space, therefore we need to define a family of functions (based on scaling) which are a basis; they are called the wavelet functions and the corresponding analysis the multi-resolution analysis.

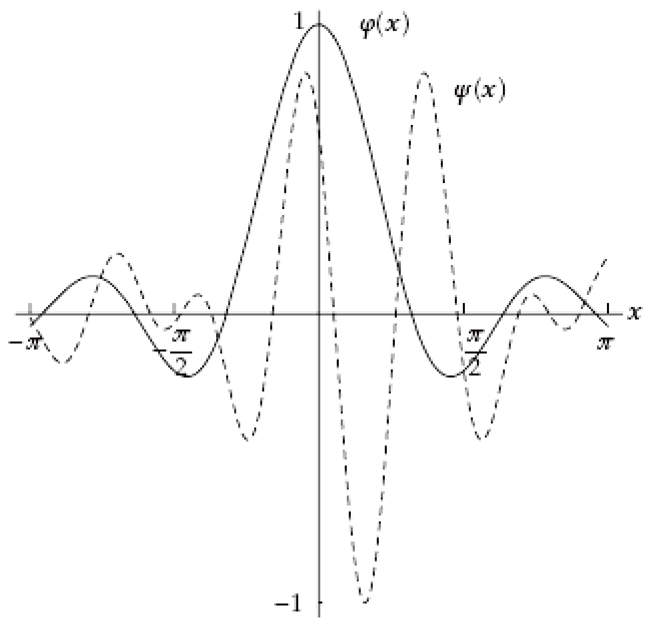
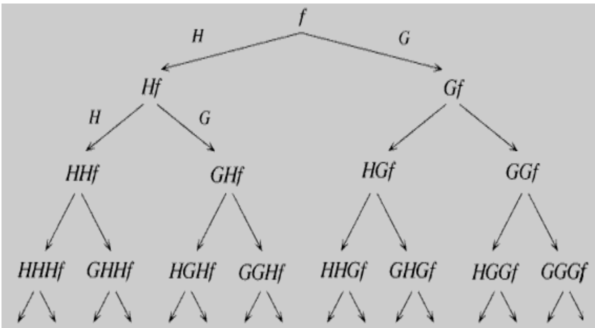


Figure 2.5: Shannon scaling function φ(x) (thick line) and wavelet (dashed line) $\psi(x)$

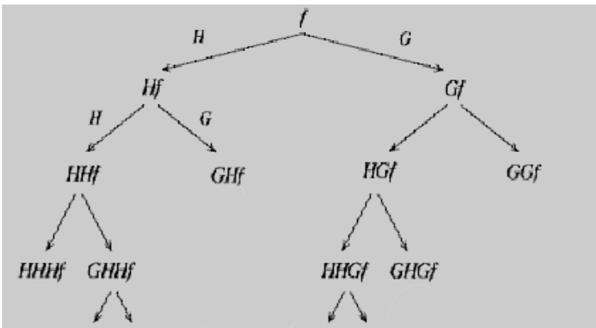
(Source: C.Cattani,2006)

2.6 Wavelet Packets

Wavelet packets decompose the low frequency component as well as the high frequency component in every sub-bands (Coifman,1992). Such adaptive expansion can be represented with binary trees where each sub-band high or low frequency component is a node with two children corresponding to the pair of high and low frequency expansion at the next scale. An admissible tree for an adaptive expansion is therefore defined as a binary tree where each node has either *0* or *2* children, as illustrated in Figure 2.8. The number of all different wavelet packet orthogonal basis equals to the number of different admissible binary trees, which is of the order of *22J,* where *J* is the depth of decomposition.



(a)



(b)

Figure 2.6: (a) Wavelet packets decomposition tree. (b) An example of an orthogonal basis tree with wavelet packets decomposition

(Source: Coifman,1995)

Obviously, wavelet packets provide more flexibility on partitioning the spatial-frequency domain, and therefore improve the separation of noise and signal into different sub-bands in an approximated sense (this is referred to the near-diagonalization of signal and noise). This property can greatly facilitate the enhancement and de-noising task of a noisy signal if the wavelet packets basis are selected properly (Coifman,1995). A fast algorithm for wavelet-packets best basis selection was introduced by Coifman and Wickerhauser (Coifman,1995). This algorithm identifies the “best” basis for a specific problem inside the wavelet packets dictionary according to a criterion that is minimized. This cost function typically reflects the entropy of the coefficients or the energy of the coefficients inside each sub-band and the optimal choice minimizes the cost function comparing values at a node and its children. The complexity of the algorithm is $0(N \log N)$ for a signal of N samples.

2.7 Wavelet Packet Analysis

Wavelet Packets Analysis (WPA) is a generalisation of wavelet analysis offering a richer decomposition procedure. In the orthogonal wavelet decomposition procedure, the generic step splits the approximation coefficients into two parts. After splitting; obtain a vector of approximation coefficients and a vector of detail coefficients, both at a coarser scale. The information lost between two successive approximations is captured in the detail coefficients

Then next step consists on splitting the new approximation coefficient vector, successive details are never reanalysed. In the corresponding wavelet packet situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting. This offers the richest analysis, the complete binary tree is produced as shown in figure 2.7. The comparison between a time-scale tiling plane of wavelets and wavelet packets is depicted in figure 2.8.

The basic functions may be denoted *wn* , where *n* ³ 0 is a nominal frequency index. They satisfy a generalisation of the two-scale equations (3.1), (3.2):

$$w_n = \sqrt{2}\sum_{k\in Z} h_k w_n\,(2x-k) \tag{3.1}$$

$$w_{n+1}(x) = \sqrt{2}\sum_{k\in Z} g_k w_n(2x-k)\; n = 0,1,2\ldots \tag{3.2}$$

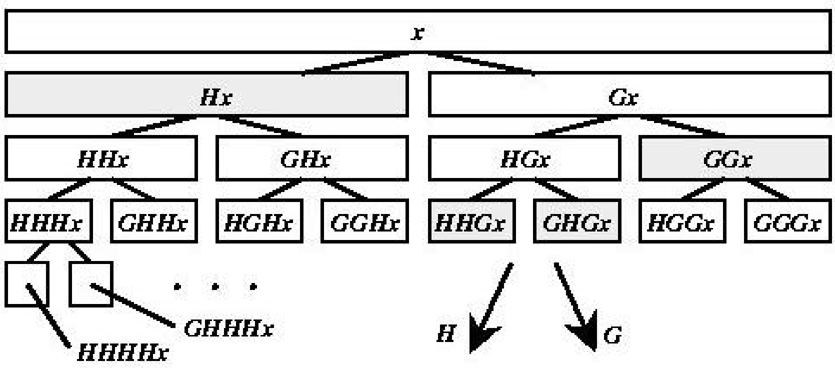
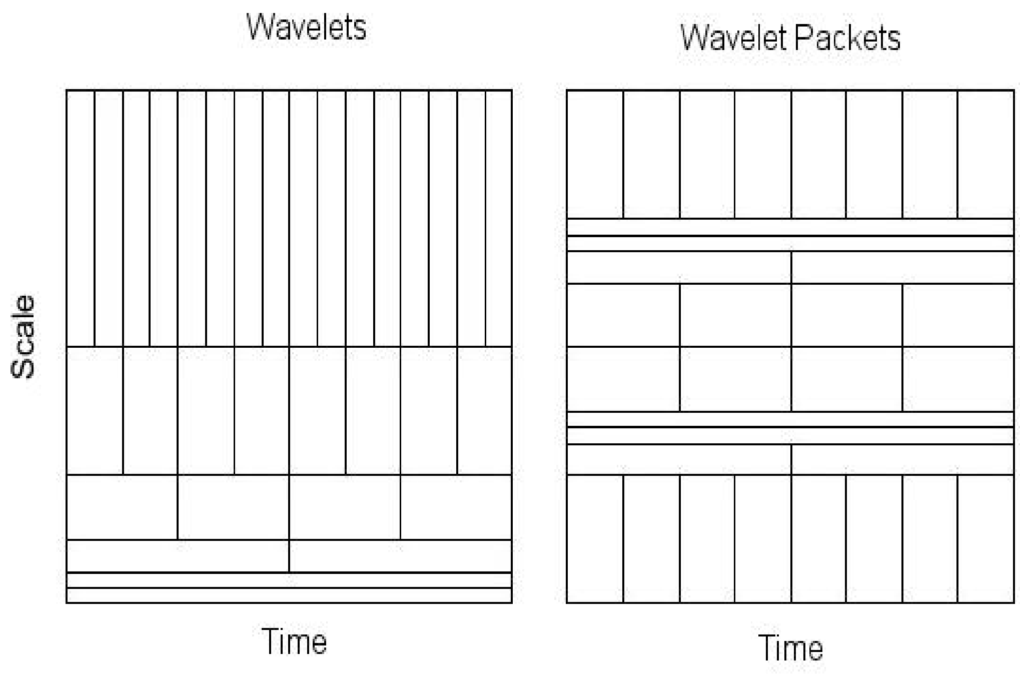


Figure 2.7: The wavelet packet decomposition using operator notations

The initial function $w_0 = \phi$ is just the scaling function. The analysing function called wavelet packet atoms are given in orthogonal case as Wickerhauser

$$w_{j,k,n}(x) = 2^{-\frac{j}{2}} w_n(2^{-j}x - k \qquad (3.3)$$



(a) (b)

Figure 2.8: The comparison between (a) a time-scale tiling plane of wavelets and (b) wavelet packets

2.8 Type of Wavelet

There is several type of wavelet;

- Haar wavelet
- Morlet wavelet
- Coiflet wavelet
- Mexican Hat wavelet
- Deubecius wavelet

2.8.1 Haar wavelet

In mathematics, the Haar wavelet is a certain sequence of functions. It is now recognised as the first known wavelet. This sequence was proposed in 1909 by Alfréd Haar. Haar used these functions to give an example of a countable orthonormal system for the space of square-integrable functions on the real line. The study of wavelets, and even the term "wavelet", did not come until much later. The Haar wavelet is the simplest possible wavelet. The technical disadvantage of the Haar wavelet is that it is not continuous, and therefore not differentiable (Haar,1910).

The Haar wavelet's mother wavelet function $\psi(t)$ can be described as:

$$\psi(t) = \begin{cases} 1 & 0 \leq t < \frac{1}{2}, \\ -1 & \frac{1}{2} \leq t < 1, \\ 0 & otherwise \end{cases} \quad (4.1)$$

and its scaling function $\phi(t)$ can be described as

$$\phi(t) = \begin{cases} 1 & 0 \leq t < 1, \\ 0 & otherwise \end{cases} \quad (4.2)$$

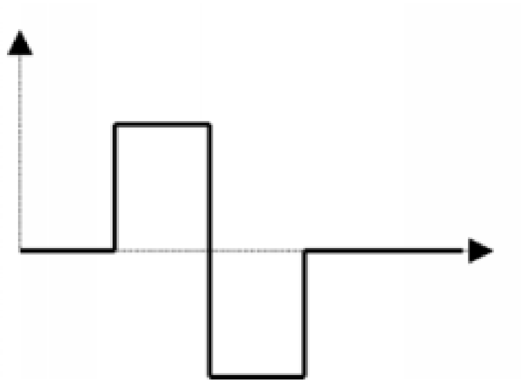


Figure 2.9: The Haar wavelet

(Source: http://research.edm.uhasselt.be)

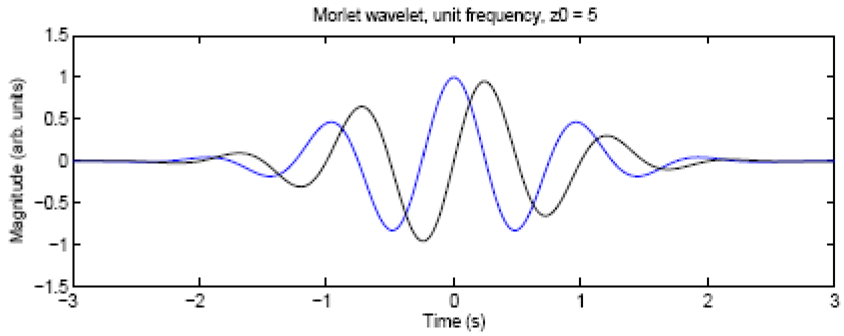
2.8.2 Morlet Wavelet

The Morlet wavelet is complex-valued, and consists of a Fourier wave modulated by a Gaussian envelope of width z_0/π:

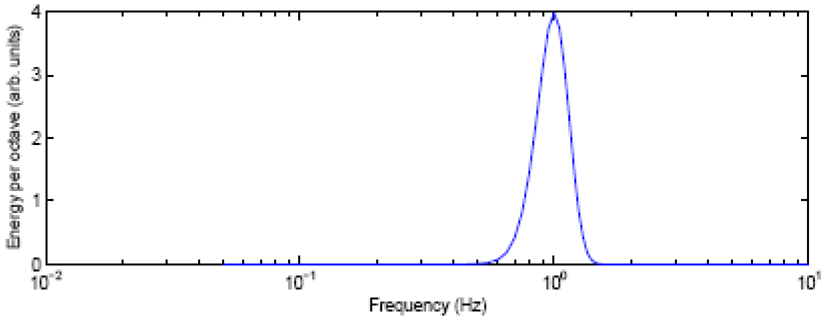
$$\psi M,_{z_0}(t) = (e^{2i\pi t} - e^{-\frac{z_0^2}{2}})e^{-2\pi^2 t^2/z_0^2} \qquad (5.1)$$

The envelope factor z_0 controls the number of oscillations in the wave packet; a value of $z_0 = 5$ is generally adopted, with the result shown elsewhere in these pages. The correction factor $e^{-\frac{z_0^2}{2}}$, making the wavelet admissible, is very small for $z0 \geq 5$ and often neglected. The Fourier transform is

$$\psi M,_{z0} = \frac{z_0}{2\sqrt{\pi}} e^{-\frac{z_0^2}{2}(1+\omega^2)}(e^{-z_0^2\omega} - 1) \qquad (5.2)$$



(a)

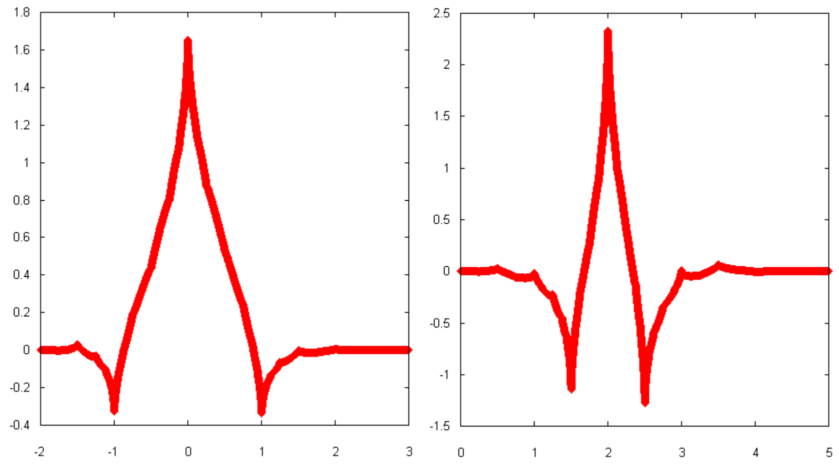


(b)

Figure 2.10: Real (a) and imaginary part (b) of the Morlet wavelet for $z_0 = 5$.

2.8.3 Coiflet Wavelet

Coiflets are discrete wavelets designed by Ingrid Daubechies, at the request of Ronald Coifman, to have scaling functions with vanishing moments. The wavelet is near symmetric; their wavelet function have N / 3 vanishing moments and scaling functions N / 3−1, and has been used in many applications using Calderón-Zygmund Operators (G. Beylkin, R. Coifman, and V. Rokhlin ,1991).



(a) (b)

Figure 2.11: Coiflet wavelet (a) Father function and (b) Wavelet function

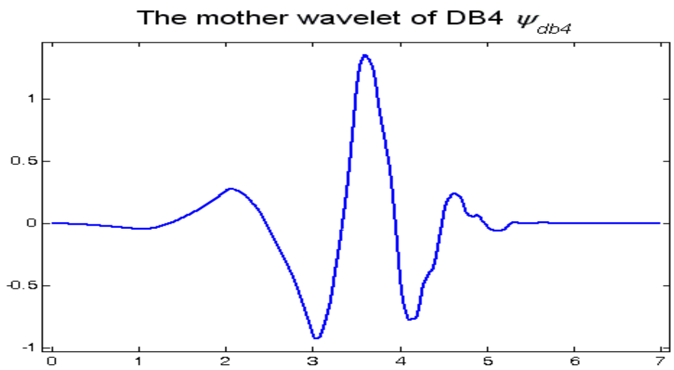
2.8.4 Daubechies Wavelet

Named after Ingrid Daubechies, the Daubechies wavelet is a wavelet used to convolve image data. The wavelets can be *orthogonal*, when the scaling functions have the same number of coefficients as the wavelet functions, or *biorthogonal*, when the numbers of coefficients differ.

In general Daubechies wavelet has extremal phase and highest number of vanishing moments for defined support width. The wavelet is also easy to put into practice with minimum-phase filters.

The Daubechies wavelets are chosen to have the highest number *A* of vanishing moments, (this does not imply the best smoothness) for given support width *N=2A*, and among the 2^{A-1} possible solutions the one is chosen whose scaling filter has extremal phase. The wavelet transform is also easy to put into practice using the fast wavelet transform. Daubechies wavelets are widely used in solving a broad range of problems,self-similarity properties of a signal or fractal problems, signal discontinuities, etc.

Daubechies constructed the first wavelet family of scale functions that are orthogonal and have finite vanishing moments, compact support (Daubechies.I,1992). This property insures that the number of non-zero coefficients in the associated filter is finite. This is very useful for local analysis. It is also the only symmetric wavelet in the Daubechies family and the only one that has an explicit expression in discrete form.



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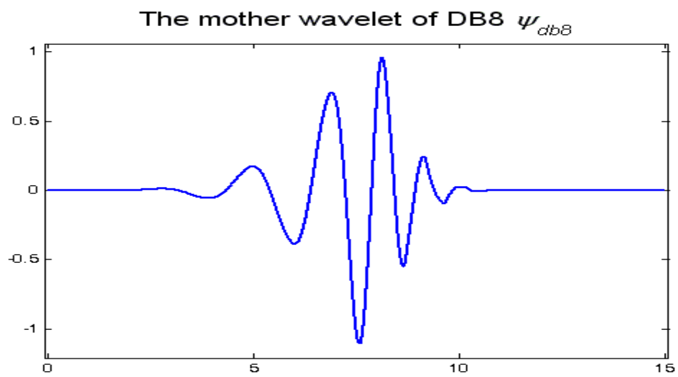


(b)

Figure 2.12: Mother wavelet functions DB4, and DB8, respectively.

The Daubechies wavelet transforms are defined in the same way as the Haar wavelet transform by computing the running averages and differences via scalar products with scaling signals and wavelets. For higher order Daubechies wavelets ψ *dbN, N* denotes the order of the wavelet and the number of the vanishing moments. The regularity increases with the order, as shown in Fig. 2.12.

The support length is $2N-1$. The length of the associated filter is twice as the number of the vanishing moments, 2N. The approximation and detail coefficients are of length floor $(\frac{n-1}{2})$ + N, if n is the length of (*f(t)*). This wavelet type has balanced frequency responses but non-linear phase responses. The regularity of the wavelets increases with the order. Figs. 1(b) and 1(c) show the wavelets DB4 and DB8. The wavelets with fewer vanishing moments give less smoothing and remove less details, but the wavelets with more vanishing moments produce distortions (Ashish Khare and Uma Shanker Tiwary,2005)

2.8.5 Mexican Hat Wavelet

In mathematics and numerical analysis, the Mexican hat wavelet is the negative normalized second derivative of a Gaussian function, up to scale and normalization, the second Hermite function. It is a special case of the family of continuous wavelets (wavelets used in a continuous wavelet transform) known as Hermitian wavelets. It is usually only called this in the Americas, due to cultural association. In technical nomenclature this function is known as the Ricker wavelet**,** where it is frequently employed to model seismic data.

$$\psi(t) = \frac{1}{\sqrt{2\pi\sigma^3}} \left(1 - \frac{-t^2}{\sigma^2}\right) e^{\frac{-t^2}{2\sigma^2}} \qquad (6)$$

The equation above describe the shape of the Mexican Hat wavelet

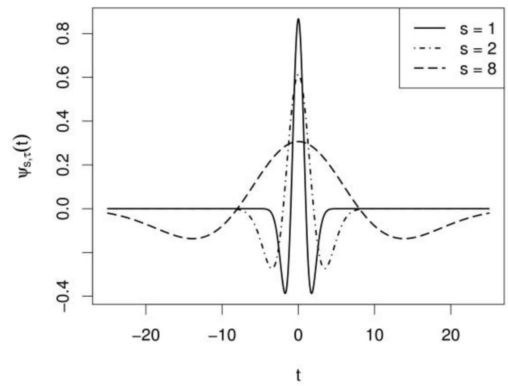


Figure 2.13: The Mexican Hat wavelet

(Source: http://www.biomedcentral.com)

The hyper dimensional generalization of this wavelet is called the Laplacian of Gaussian function. In practice, this wavelet is sometimes approximated by the Difference of Gaussians function, because it is separable and can therefore save considerable computation time in two or more dimensions. The scale normalised Laplacian (in L_1-norm) is frequently used as a blob detector and for automatic scale selection in computer vision applications.

CHAPTER III

METHODOLOGY

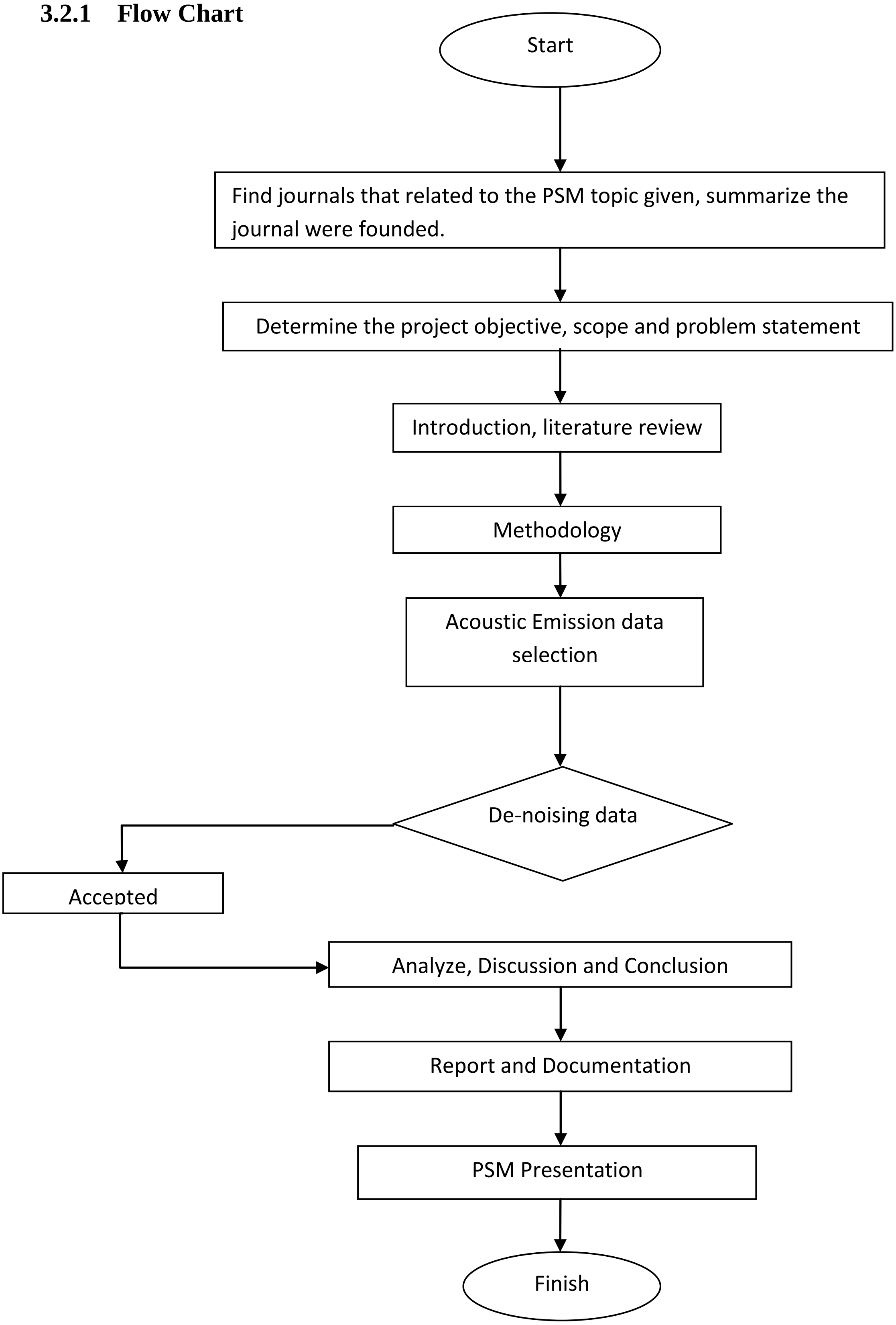
3.1 Introduction

In general, this project involves selection, de-noising the acoustic emission (AE) data taken from M.H.Zohari,2008 experiment to determine the pipe surface roughness and analyzing the result. The software that was used to de-noise the acoustic emission data is MATLAB R2008a. The data were de-noised by using One-Dimensional (1-D) Wavelet Packet Analysis contain in Matlab R2008a.

3.2 Flow Chart Methodology

To achieve the objectives of the project, a methodology were construct base on the scope of product as a guiding principle to formulate this project successfully. The important of this project is to de-noise and analyze the signal produce by the acoustic sensor. The terminology of works and planning of this project show in the flow chart below. This is very important to make sure that the experiment in the right direction.

3.2.1 Flow Chart



3.3 Gantt Chart

Gantt Chart For FYP 1

No.	Activities/weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Title														
2	Objective and Scope														
3	Introduction														
4	Literature Review														
5	Define Objective and Scope														
6	Methodology														
7	Presentation Preparation														
8	FYP 1 Presentation														

Gantt Chart For FYP2

No.	Activities/weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Literature Study																
2	Analysis Project																
3	Collect the Data																
4	Analysis of Data and result																
5	Interprets Data																
6	Conclusion																
7	Final presentation																
8	Preparing and Submit Report																

3.4 Signal Analysis Methodology

The study mainly deals with the removal of noise and recovering of signal from the noisy data using wavelet transform. Before discussing about the work, the method of de-noising is described.

3.4.1 De-Noising Of Signal

The model for the noisy signal is expressed as

$$S(n) = f(n) + \sigma e(n) \qquad (7)$$

where time *n* is equally spaced. In the simplest model, suppose that *e(n)* is a Gaussian white noise and *s* is the noise level, the de-noising objective is to suppress the noise part of the signal *s* and to recover *f*. The de-noising procedure proceeds in three steps, namely: (a) decomposition, (b) detail coefficients thresholding, and (c) reconstruction.

3.4.2 Signal Analysis

Test signals for different conditions are obtained. The test signals are corrupted by random noise present at all instants of time. The signals are extracted from noisy signals. The Discrete Wavelet Transform (DWT) is applied on the test signal. The DWT of the test data with different wavelets are computed, and after threshold, the signal is reconstructed. The reconstructed signals are devoid of noise but there exits slight variations between one signal and the other due to differences in the wavelets employed to decompose the test data signal. The de-noised signals are then selected. If more than one signal is selected, an average of all the selected signals is computed and is displayed as the extracted signal.

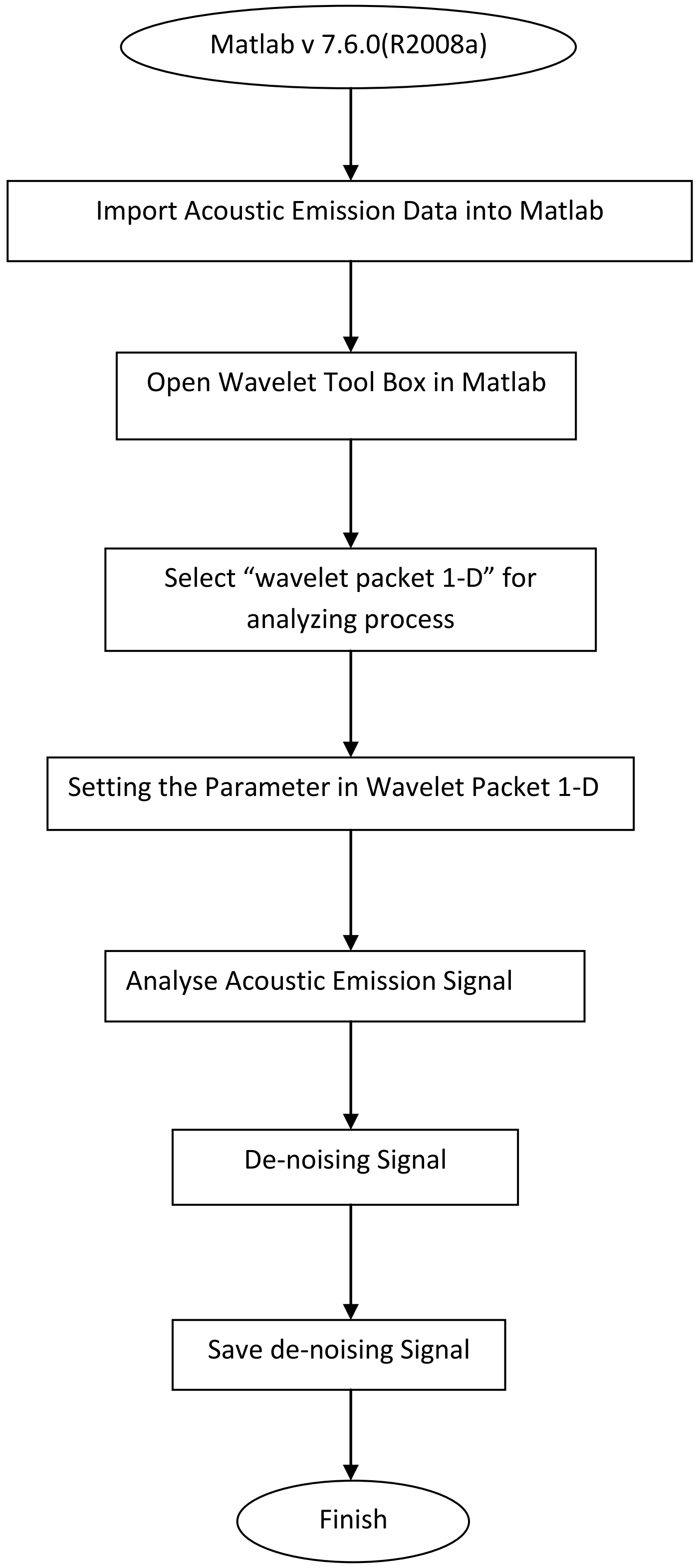
The signatures of different test signals are typically low-frequency signals enveloped by relatively high-frequency background noise. So to de-noise these signals, the detail coefficients are heavily thresholded. In the present study, all the detail coefficients, at all the levels, are made zero and the signal is reconstructed back.

In this experiment, the acoustic emission data collected from M.H.Zohari(2008) experiment to determine the surface roughness were de-noising. The software using is MATLAB R2008a and data were de-noising using one dimensional (1-D) wavelet packet analysis that contain in MATLAB R2008a.

An appropriate setting for data analysis was making. Data was analyses by using db2 until db12 wavelet, ten different db levels were used to obtain the objective of this experiment which is to select the best daubechies and the entropy Shannon selected. For the first experiment, one set of data is selected and 30 signals were taken to be analyse and then, the data de-noise using different daubechies type from db2 until db 12.

For the second experiment, before the de-noising process, data were analyse to get value of Peak amplitude, Root Mean Square (RMS) and Energy. The purpose is to compare the value obtain before and after the de-noising process.

3.4.3. Step for De-noising Process



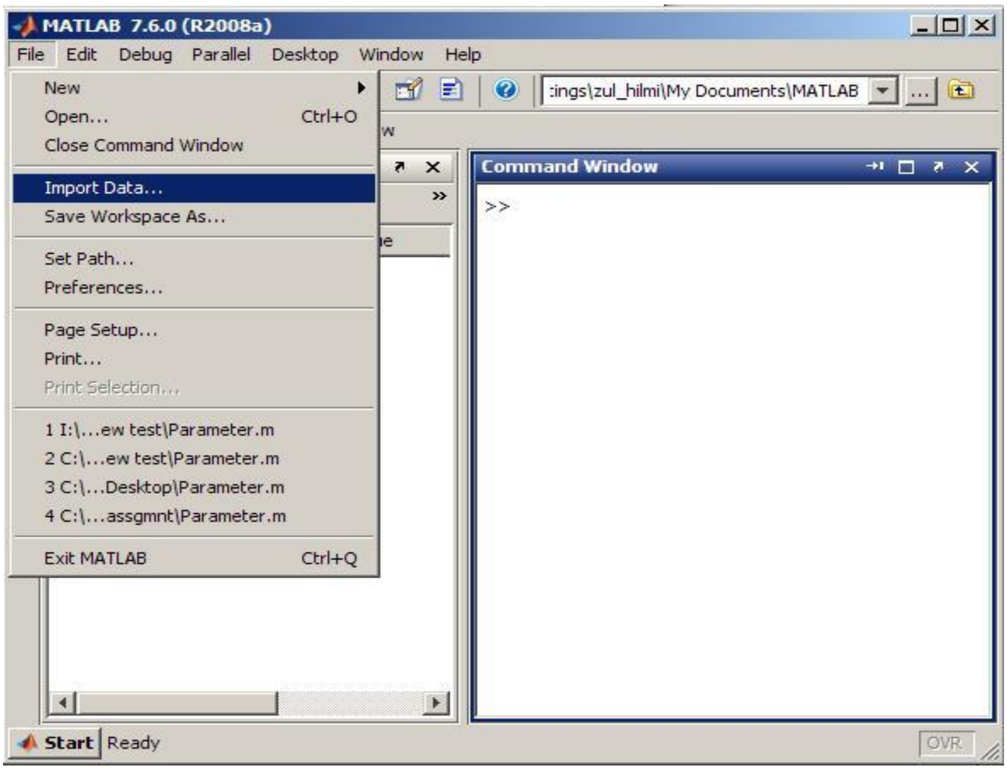


Figure 3.1: Import an AE data into Matlab

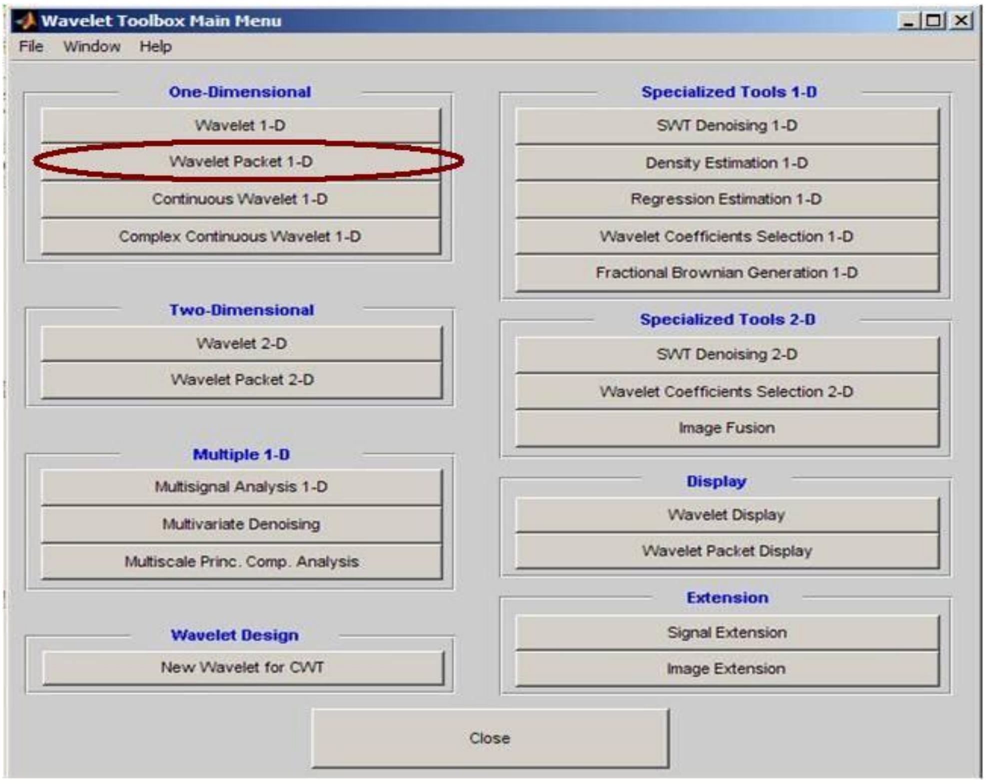


Figure 3.2: Wavelet Packet 1-D in Wavelet Tool Box

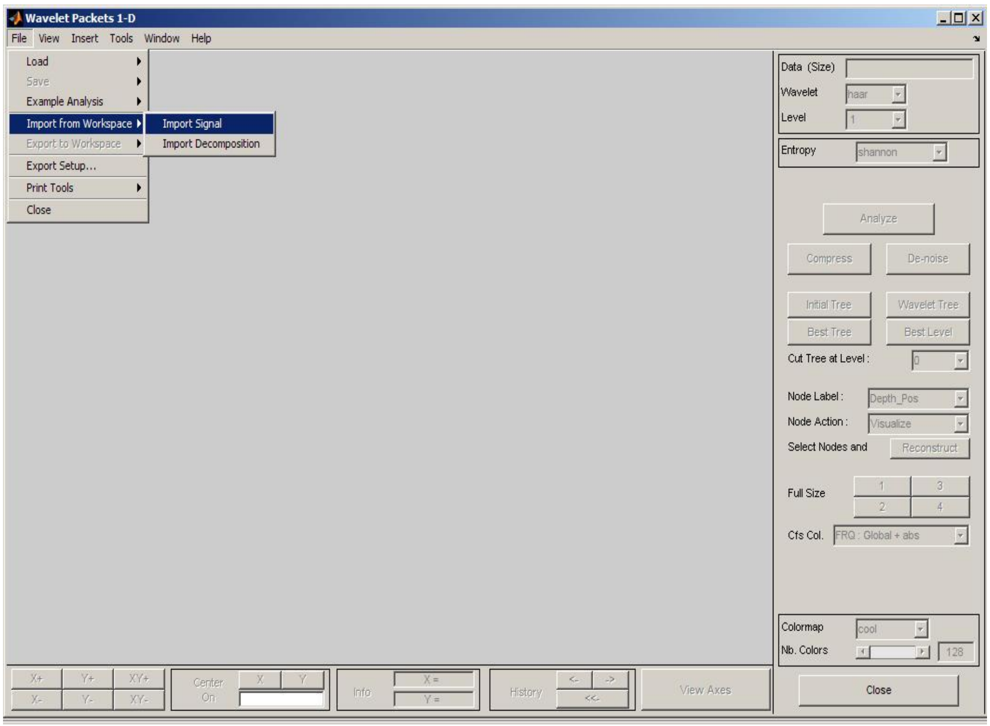


Figure 3.3: Import AE Signal into Wavelet Packet 1-D

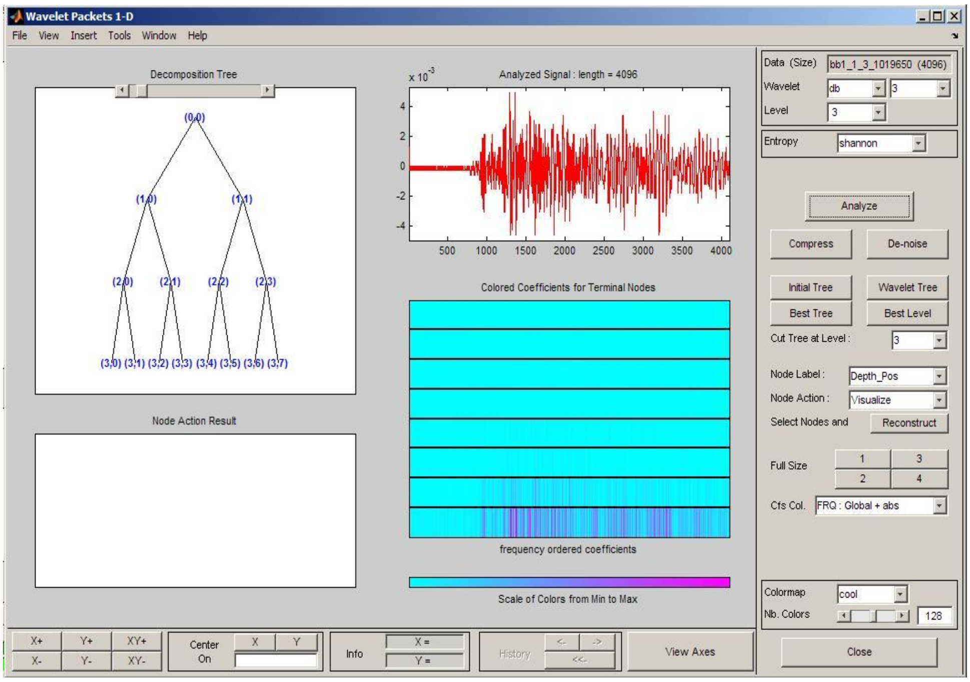


Figure 3.4: Setting the Parameter to De-Noise the Signal

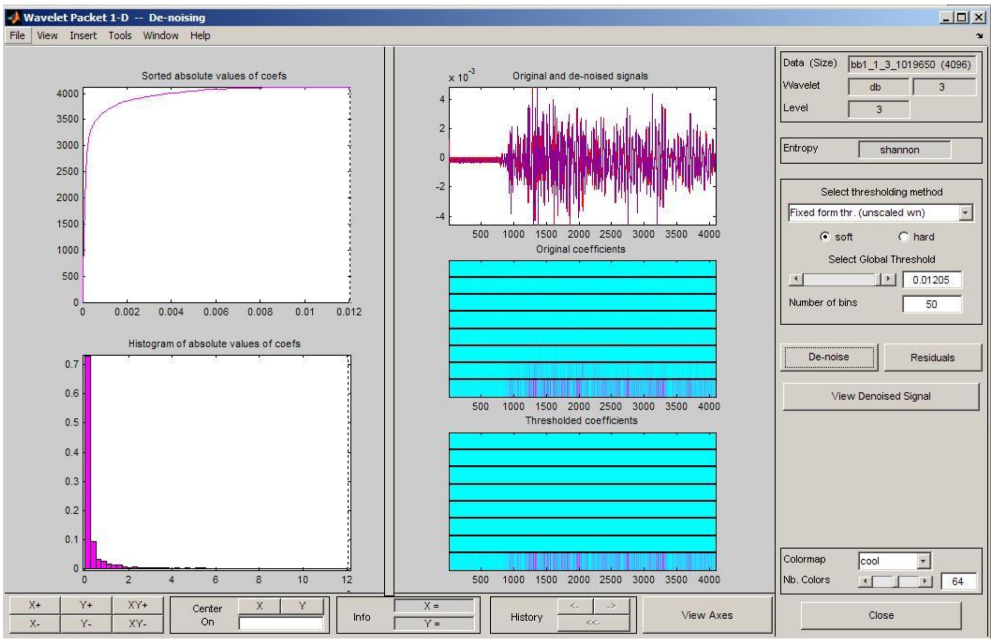


Figure 3.5: Analye the Signal

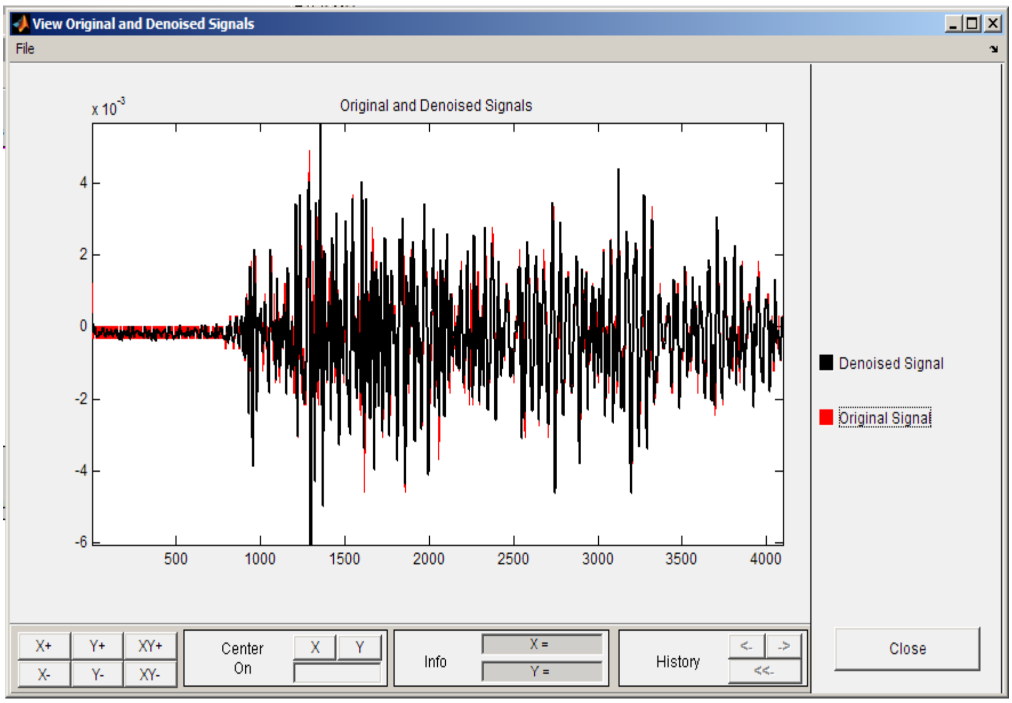


Figure 3.6: AE Signal Before and after De-noising Process

CHAPTER IV

RESULT AND DISCUSSION

4.1 Introduction

As mention in the previous chapter, two experiments were conduct to achieve the objective of the project. Note that, some of the result from this experiment show the same pattern as what have been done by M.H.Zohari,2008.

The objectives of this project are to determine the best daubechies wavelet for de-noising acoustic emission data and to differentiate the acoustic emission data before and after de-noising One Dimensional (1-D) wavelet packet analysis. Overall of the de-noising process takes about two month to be completed. In the next topics show the result of all the experiment.

4.2 De-noising Acoustic Emission Data (I)

The acoustic emission data that taken from M.H.Zohari,2008 for this experiment consist a data taken from two different surface condition which is rough and smooth pipe surface condition. For rough pipe surface, the acoustic emission data can be separate into two type of flow which is high flow rate and low flow rate. The same goes to the other one and it is taken from four different points.

For experiment 1, a set of data was taking from rough pipe surface for low flow rate, 30 signals were taken to be analysed. Before de-noising process, the value of the energy of the signal was taken using MATLAB coding (see appendix 1). All the signals were de-noise using one dimensional (1-D) wavelet packet analysis contain in MATLAB R2008a. Ten different daubechies level from db2 until db12 were used. After all signal were de-noise the energy value of the signal were taken again, this is to differentiate the energy different before and after de-noising process. The result showed in table 4.3.

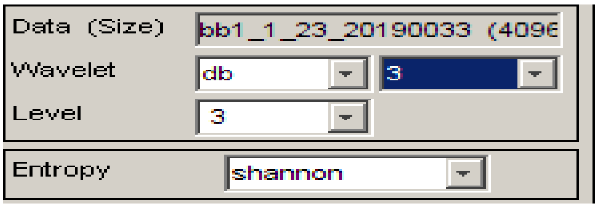


Figure 4.1: Example of setting that used to de-noise the acoustic emission data

Table 4.1: Result From De-Noising Process (Energy Lost After De-Noising Process)

Daubechies Type	No. of Data					
	2	3	4	5	6	7
Type 2	0.1056	0.1050	0.0488	0.2344	0.0276	0.0315
Type 3	0.0730	0.0572	0.0211	0.1502	0.0046	0.0146
Type 4	0.0480	0.0447	0.0069	0.1002	-0.0039	0.0027
Type 5	0.0420	0.0286	0.0102	0.0933	-0.0024	0.0020
Type 6	0.0354	0.0350	-0.0001	0.0776	-0.008	-0.0014
Type 7	0.0287	0.0183	0.0059	0.0692	-0.008	-0.0026
Type 8	0.0291	0.0323	-0.0040	0.0665	-0.0107	-0.0022
Type 9	0.0201	0.0133	0.0039	0.0509	-0.0069	-0.0049
Type 10	0.0227	0.0291	-0.0041	0.0612	-0.0116	-0.0034
Type 11	0.0168	0.0111	0.0017	0.0399	-0.0084	-0.0062
Type 12	0.0176	0.0260	-0.0041	0.0568	-0.0119	-0.0048

Table 4.1: Continued

Daubechies Type	No. of Data					
	8	9	10	11	12	13
Type 2	0.0557	0.1852	0.0429	-0.0325	1.0664	0.0823
Type 3	0.0233	0.1568	0.0325	0.0482	0.4858	0.0533
Type 4	0.0156	0.0731	-0.0020	0.0252	0.6006	0.0390
Type 5	0.0079	0.0913	0.0087	0.0236	0.3081	0.0338
Type 6	0.0108	0.0492	-0.0067	0.0130	0.4835	0.0188
Type 7	0.0026	0.0643	-0.0004	0.0123	0.3025	0.0311
Type 8	0.0086	0.0372	-0.0049	0.0101	0.3865	0.0115
Type 9	0.0002	0.0439	-0.008	0.0031	0.2853	0.0281
Type 10	0.0056	0.0305	-0.0036	0.0078	0.2932	0.0059
Type 11	-0.0002	0.0325	-0.0117	-0.0031	0.2824	0.0248
Type 12	0.0030	0.0252	-0.0026	0.0073	0.2140	0.0046

Table 4.1: Continued

Daubechies Type	No. of Data					
	14	15	16	17	18	19
Type 2	0.0550	0.3585	0.0472	0.2567	0.1667	0.6369
Type 3	0.0244	0.2225	0.0275	0.1191	0.0849	0.619
Type 4	0.0075	0.1592	0.0130	0.0829	0.0589	0.2994
Type 5	0.0030	0.1474	0.0091	0.0503	0.0507	0.3848
Type 6	0.0023	0.1207	0.0059	0.0514	0.0344	0.2202
Type 7	-0.0023	0.1278	0.0040	0.0383	0.0423	0.3023
Type 8	-0.0008	0.0996	0.0040	0.0346	0.0246	0.1970
Type 9	-0.0051	0.1084	0.0003	0.0344	0.0346	0.2361
Type 10	-0.0022	0.0864	0.0020	0.0238	0.0206	0.1706
Type 11	-0.0050	0.0923	-0.0029	0.0362	0.0253	0.1793
Type 12	-0.0035	0.0804	0.0002	0.0116	0.0234	0.1611

Table 4.1: Continued

Daubechies Type	No. of Data					
	20	21	22	23	24	25
Type 2	0.0742	0.0486	0.0614	0.0388	0.0627	0.4174
Type 3	0.0545	0.0305	0.0250	0.0125	0.0390	0.2184
Type 4	0.0311	0.0114	0.0095	0.0063	0.0478	0.2135
Type 5	0.0114	0.0183	0.0063	0.0035	0.0318	0.1441
Type 6	0.0193	0.0063	0.0068	0.0004	0.0359	0.182
Type 7	0.0053	0.0112	0.0002	0.0030	0.0317	0.1315
Type 8	0.0204	0.0052	0.0025	-0.0023	0.0312	0.1485
Type 9	-0.0037	0.0069	-0.0031	0.0028	0.0322	0.1313
Type 10	0.0216	0.0066	0.0025	-0.0038	0.0258	0.1193
Type 11	-0.008	0.0025	-0.0043	0.0012	0.0323	0.1361
Type 12	0.0185	0.007	0.0004	0.0012	0.0223	0.0937

Table 4.1: Continued

Daubechies Type	No. of Data				
	26	**27**	**28**	**29**	**30**
Type 2	0.2255	0.1276	0.0585	0.017	0.8883
Type 3	0.1639	0.0855	0.0251	0.0035	0.7204
Type 4	0.0962	0.0564	0.0305	-0.0067	0.4353
Type 5	0.1056	0.0383	0.0154	-0.0067	0.4838
Type 6	0.0637	0.0411	0.0231	-0.0087	0.33
Type 7	0.0913	0.0214	0.0151	-0.0113	0.4075
Type 8	0.0495	0.0339	0.0195	-0.0101	0.2914
Type 9	0.0829	0.0113	0.0161	-0.0137	0.3369
Type 10	0.0397	0.0273	0.0154	-0.0107	0.2884
Type 11	0.0744	0.006	0.0184	-0.0145	0.2835
Type 12	0.0744	0.0223	0.0132	-0.0113	0.2906

Tables 4.1 show the energy different before and after de-noising process. AE parameter which is energy were choose between peak amplitude and Root Mean Square (RMS) amplitude because from the energy it can determine how much the energy of the acoustic emission signals were lost during de-noising process. From the result obtain in table 4.1, only daubechies type 3 or db3 contain no negative (-ve) value for energy lost after de-noising process. Base on the result, it can conclude that db3 is the best daubechies wavelet for de-noising process and the reason is; it is impossible for the energy value to be greater than before after the signal has been de-noised and hat why daubechies type 3 or db3 has been choose. Overall all the daubechies gives almost the same result but only db 3 give all positive value for de-noised signal and that why db 3 were selected as the best daubechies wavelet.

4.3 De-noising Acoustic Emission Data (II)

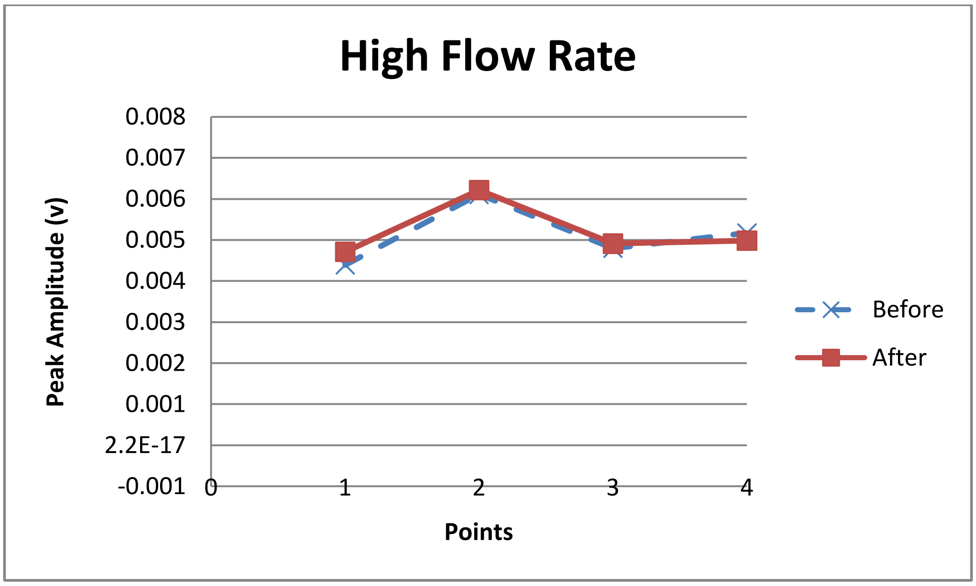
For the second test, Acoustic emission (AE) signals data taken from rough and smooth pipe with two kind of flow rate; high flow rate and low flow rate. All this data were de-noise but before that the AE parameters measured were peak amplitude RMS amplitude and energy. Table 4.2, figure 4.2, 4.3, 4.4 show the result of AE signals for data from rough inner surface pipe.

Table 4.2: Value of AE Parameter for Rough Surface Pipe

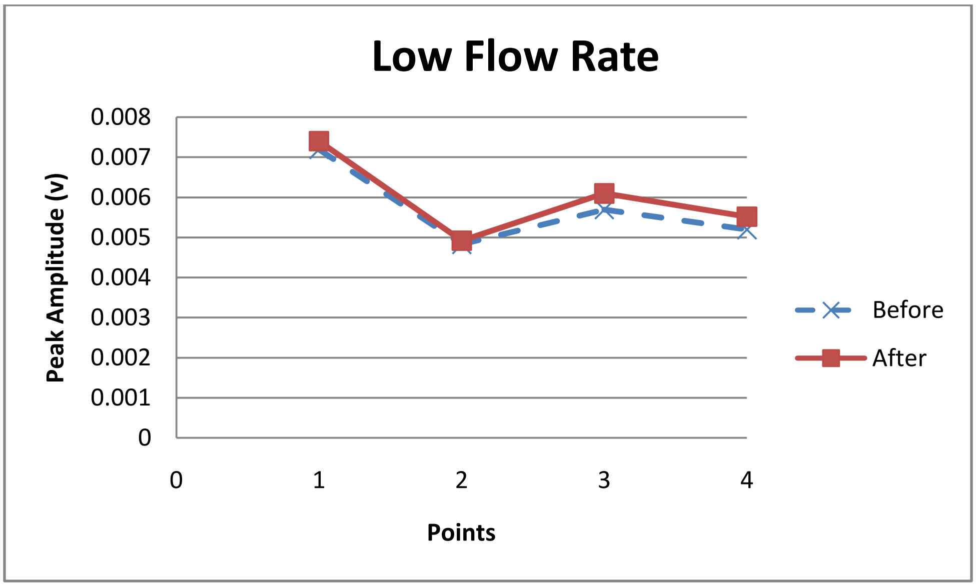
	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	High Flow Rate		High Flow Rate		High Flow Rate	
	Before	After	Before	After	Before	After
1	0.0044	0.0047	0.0011	0.0011	3.0945	3.0143
2	0.0061	0.0062	0.0015	0.0015	4.1592	4.0298
3	0.0048	0.0049	0.0013	0.0013	3.7803	3.7693
4	0.0052	0.005	0.0013	0.0013	3.7157	3.7071

Table 4.2: Continued

	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	Low Flow Rate		Low Flow Rate		Low Flow Rate	
	Before	After	Before	After	Before	After
1	0.0072	0.0074	0.0017	0.0017	4.8074	4.6834
2	0.0048	0.0049	0.0013	0.0012	3.7327	3.6793
3	0.0057	0.0061	0.0015	0.0015	4.4192	4.3255
4	0.0052	0.0055	0.0014	0.0014	4.2654	4.1753

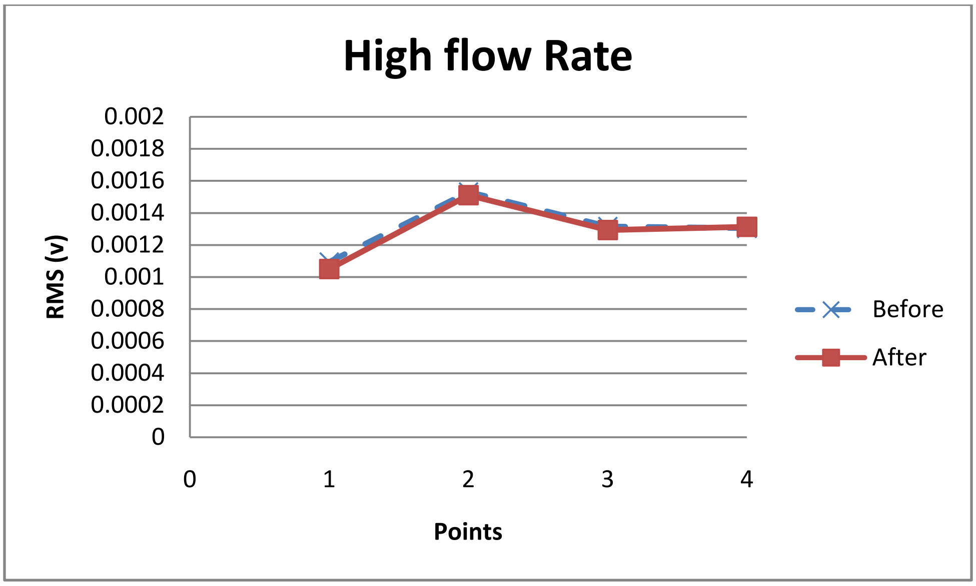


(a)

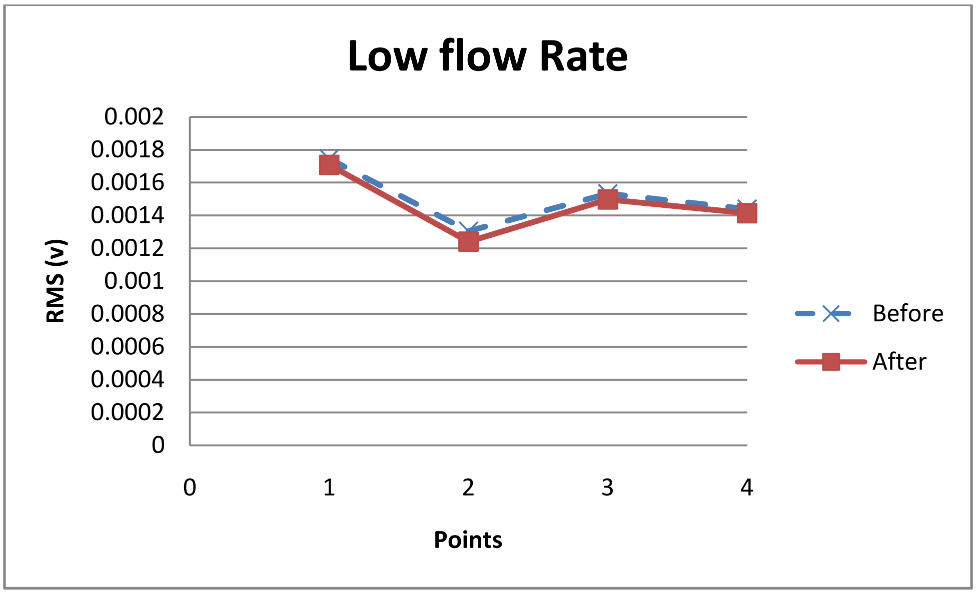


(b)

Figure 4.2: Peak Amplitude of Rough Pipe for (a) high flow rate and (b) low flow rate

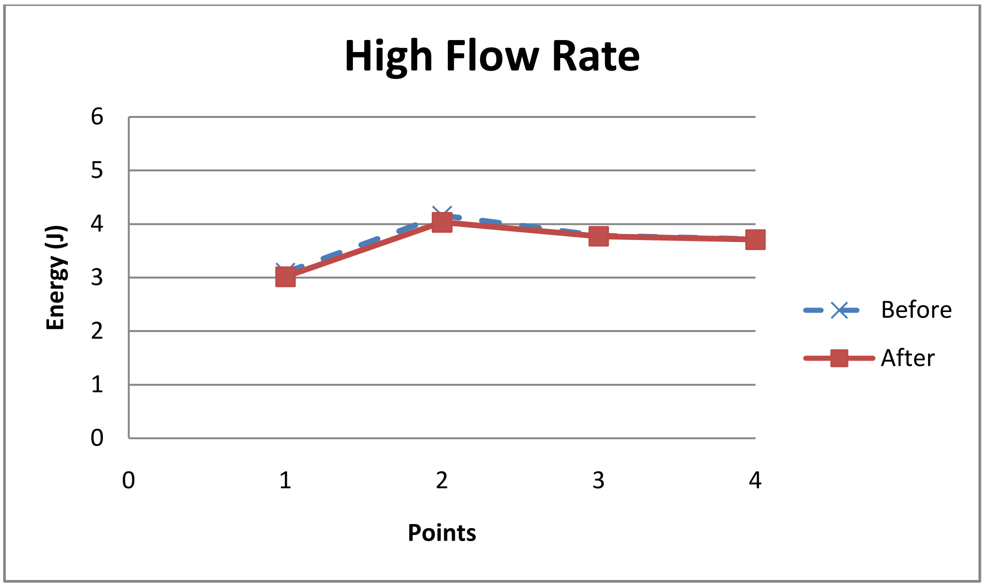


(a)

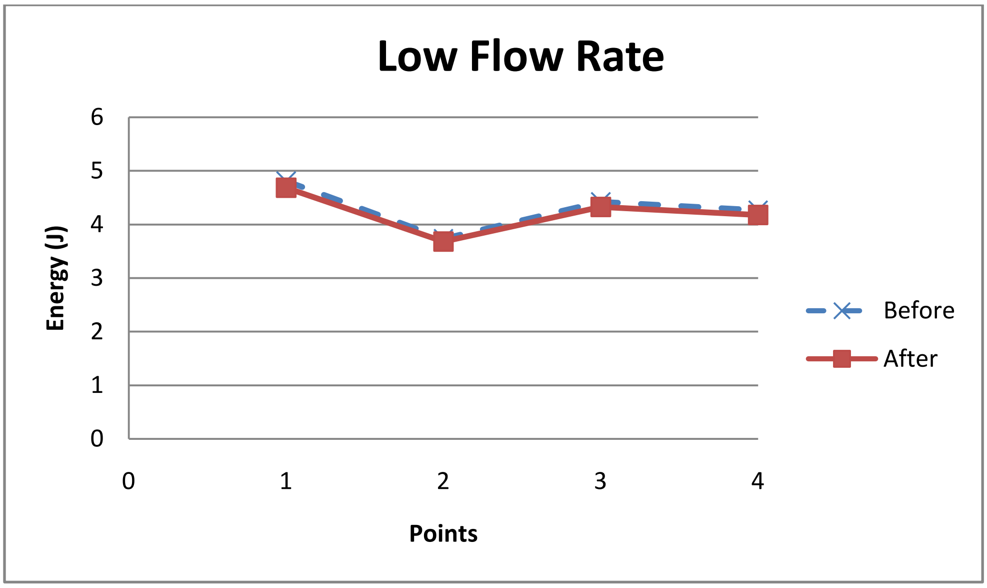


(b)

Figure 4.3: RMS amplitude of Rough Pipe for (a) high flow rate and (b) low flow rate



(a)



(b)

Figure 4.4: Energy of Rough Pipe for (a) high flow rate and (b) low flow rate

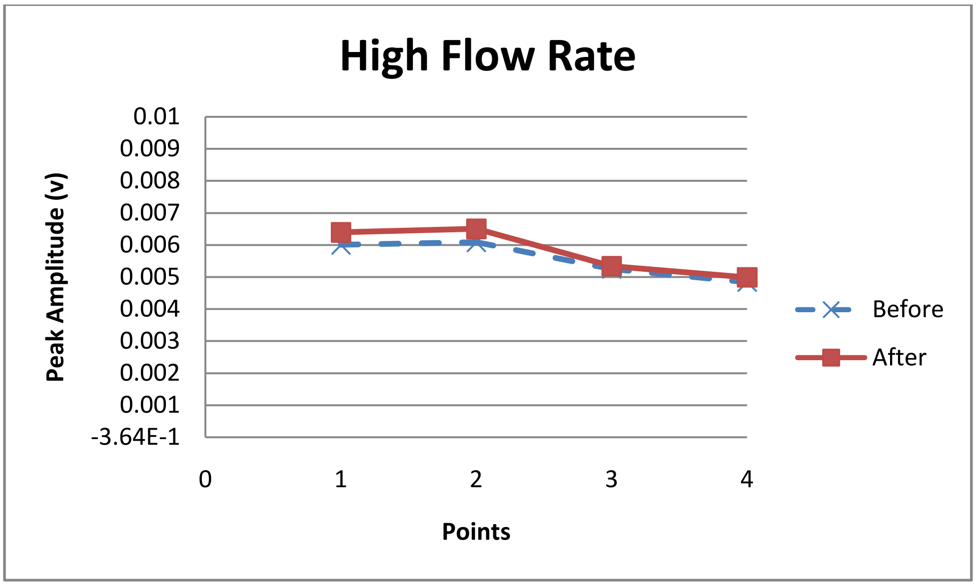
The results show that there are no significant changes in AE parameters for peak amplitude, RMS and energy. The different of AE parameters between before and after de-noising process are very small, this may be happen because the raw data are free from other unwanted signal.

Table 4.3: Value of AE Parameter for Smooth Surface Pipe

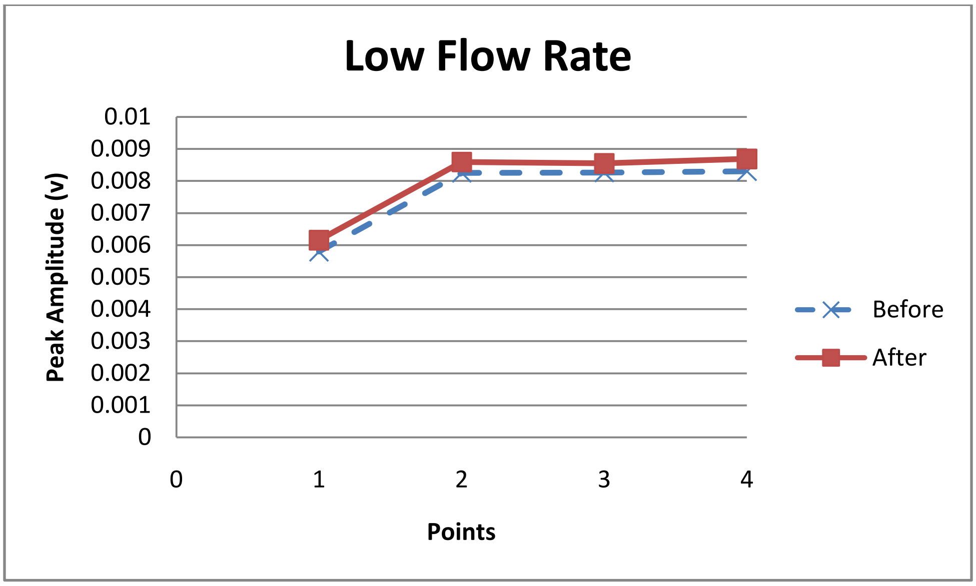
	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	High Flow Rate		High Flow Rate		High Flow Rate	
	Before	After	Before	After	Before	After
1	0.006	0.0064	0.0014	0.0014	3.9428	3.7893
2	0.0061	0.0065	0.0014	0.0014	3.9230	3.8442
3	0.0053	0.0053	0.0013	0.0012	3.6161	3.5144
4	0.0048	0.0050	0.0012	0.0012	3.4907	3.4522

Table 4.3: Continued

	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	Low Flow Rate		Low Flow Rate		Low Flow Rate	
	Before	After	Before	After	Before	After
1	0.0058	0.0062	0.0015	0.0014	4.2455	4.0586
2	0.0083	0.0086	0.0021	0.0020	5.9113	5.7056
3	0.0083	0.0085	0.0022	0.0021	6.4032	6.1224
4	0.0083	0.0087	0.0020	0.0020	5.8629	5.6111

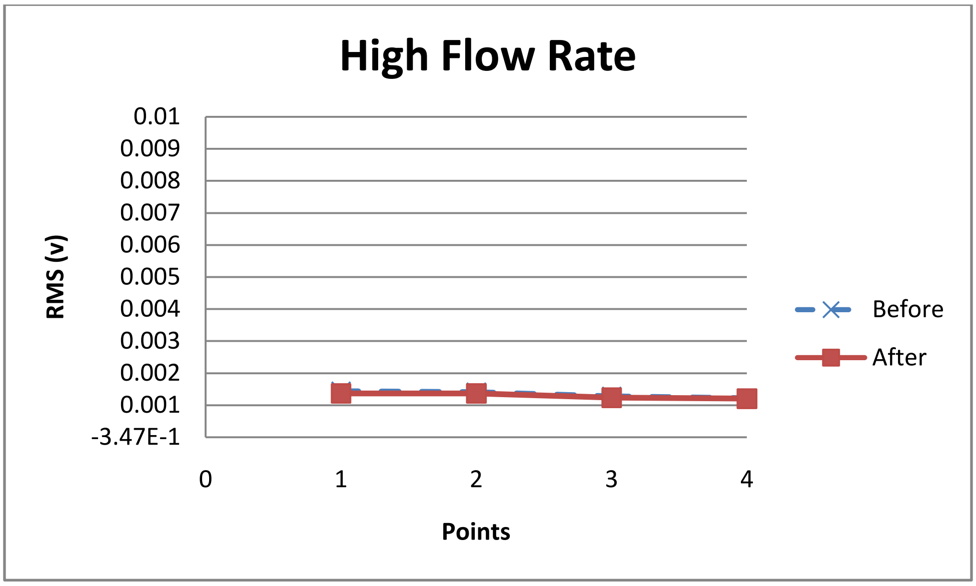


(a)

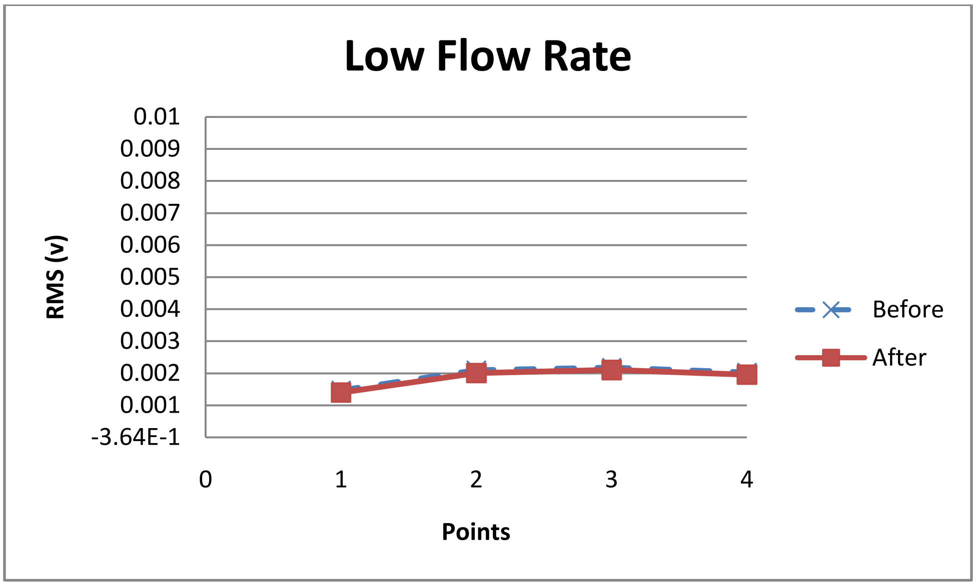


(b)

Figure 4.5: Peak Amplitude of Smooth Pipe for (a) high flow rate and (b) low flow rate

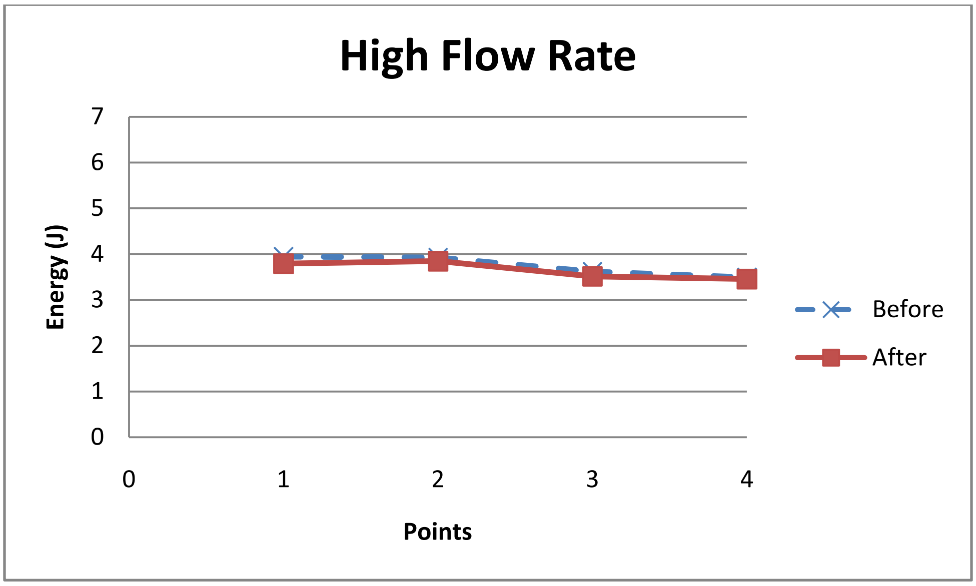


(a)

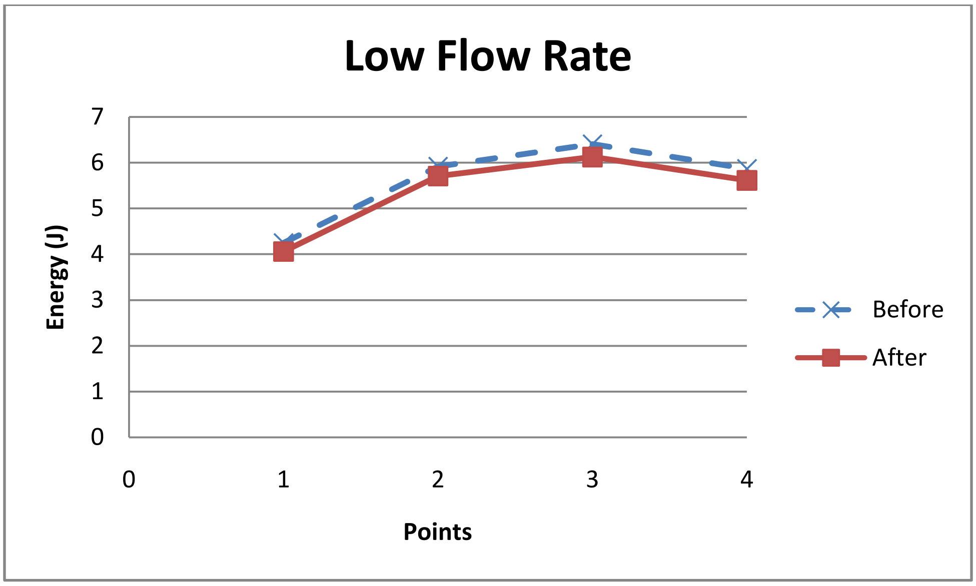


(b)

Figure 4.6: RMS amplitude of Smooth Pipe for (a) high flow rate and (b) low flow rate



(a)



(b)

Figure 4.7: Energy of Smooth Pipe for (a) high flow rate and (b) low flow rate

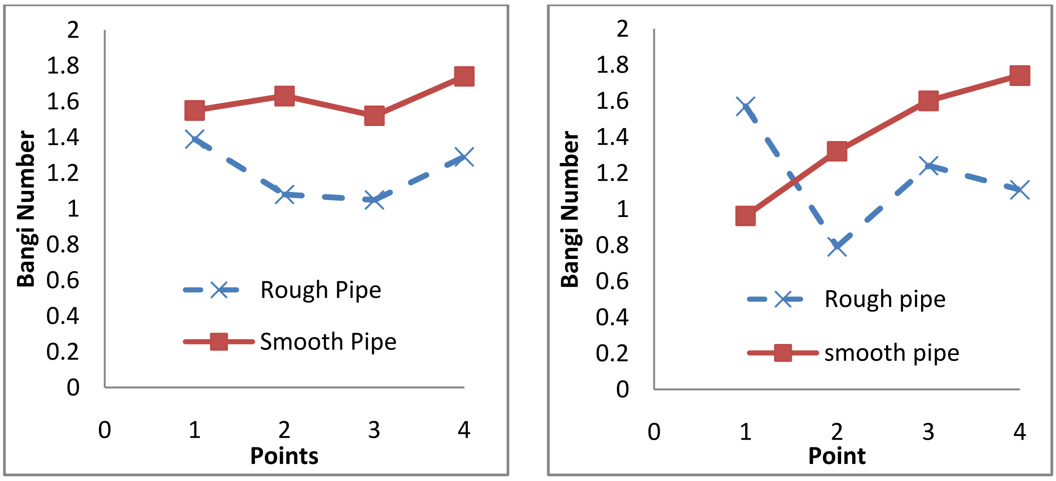
The same results show for the smooth pipe that there are no significant changes in AE parameters for peak amplitude, RMS and energy. The different of AE parameters between before and after de-noising process are very small. All set of de-noised data can be referred in appendix 2

To make the difference become more significant between smooth and rough pipe, the dimensionless number, α was introduced by M.H.Zohari,2008 knows as *Bangi* number, α can be defines as

$$\alpha = \frac{A_{Low}}{A_{High}}$$

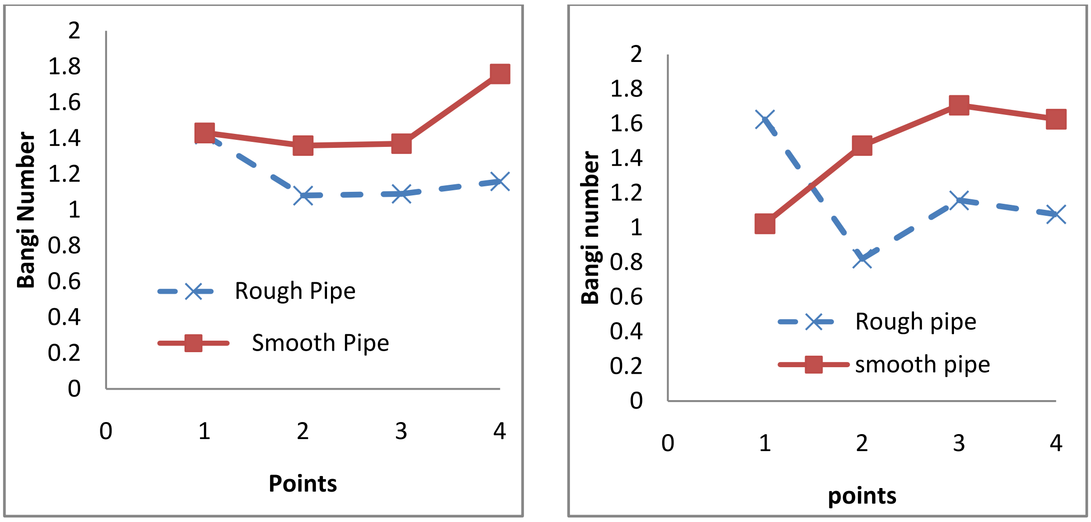
where, A_{High} is referred to value of peak amplitude, RMS amplitude and energy at high flow rate and A_{Low} is the value of peak amplitude, RMS amplitude and energy at low flow rate.

The plot of *Bangi* number, α versus of sensor for each of AE parameters were shown in figure 4.8 to 4.10 and table 4.1 and 4.2 shows the value for *Bangi* number for each point.



(a) (b)

Figure 4.8: Comparison of *Bangi* number plot for peak amplitude from a) previous result and (b) the latest result



(a) (b)

Figure 4.9: Comparison of *Bangi* number plot for RMS amplitude from a) previous result and (b) the latest result

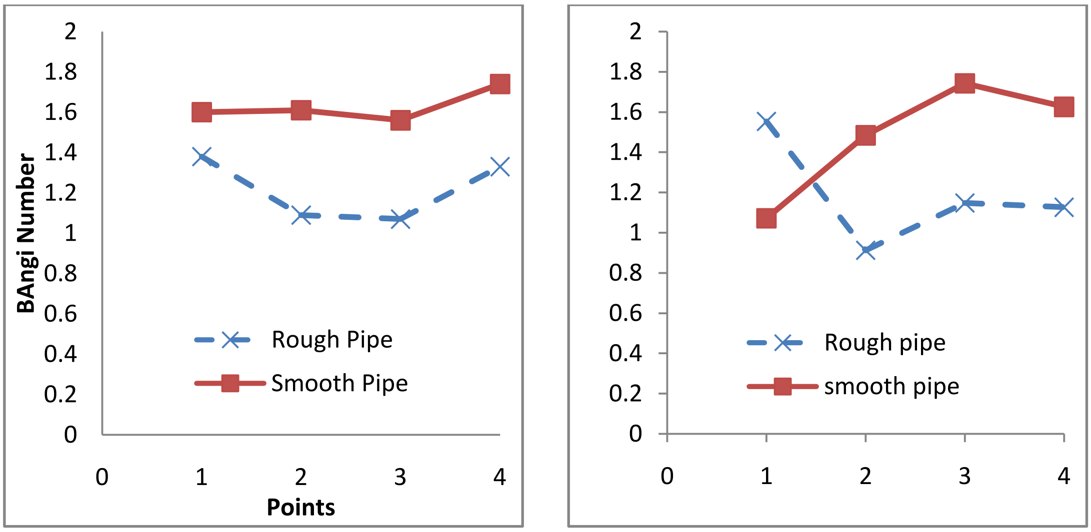


Figure 4.10: Comparison of *Bangi* number plot for energy from a) previous result and (b) the latest result

Table 4.4: *Bangi* number value for rough pipe

	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	Before	**After**	**Before**	**After**	**Before**	**After**
1	0.965	0.963	1.021	1.023	1.077	1.071
2	1.357	1.321	1.493	1.473	1.507	1.484
3	1.573	1.600	1.709	1.706	1.771	1.742
4	1.715	1.741	1.669	1.626	1.680	1.625

Table 4.5: *Bangi* number value for smooth pipe

	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	Before	**After**	**Before**	**After**	**Before**	**After**
1	1.636	1.570	1.595	1.626	1.554	1.554
2	0.790	0.791	0.851	0.821	0.897	0.913
3	1.186	1.241	1.165	1.157	1.169	1.148
4	1.004	1.107	1.103	1.077	1.148	1.126

Table 4.6: Bangi number value from (M.H.Zohari,2008)

	Peak Amplitude (v)		RMS Amplitude (v)		Energy (J)	
	Rough Pipe	**Smooth Pipe**	**Rough Pipe**	**Smooth Pipe**	**Rough Pipe**	**Smooth Pipe**
1	1.390	1.550	1.420	1.430	1.380	1.600
2	1.080	1.630	1.080	1.360	1.090	1.610
3	1.050	1.520	1.090	1.370	1,070	1.560
4	1.290	1.740	1.160	1.760	1.330	1.740

Bangi number plots for peak amplitude, RMS amplitude and energy show almost the same pattern. The pattern for peak amplitude, RMS amplitude and energy are almost same because they represent the same signal characteristic; energy level for overall acoustic signal.

Note that, there is an awkward pattern at point 1 for rough pipe in all graphs, this happen because all of data are taken from average value of 30 set of data from point 1 until 4 (for rough and smooth pipe) but the data at point 1 for rough pipe consist only 17 data and the average value of point 1 for rough pipe are taken from 17 set of data only.

From the graph of comparison of the Bangi number between the previous experiments, it have a significant different between the previous and the latest experiment. This may be happen due different set of data taken for the average value for each point and that why there are significant different between the previous experiment. Besides that, the different may be due type of daubechies use to de-noise the signal for the experiment.

CHAPTER V

CONCLUSION

5.1 Conclusion

The de-noised signal is important to analysed and identify the signature of the phenomenon during liquid flow in the pipe, pressure testing and many more. Data has been de-noising to remove the unwanted signal and to reconstruct the signals. It is important process to give the better result in the analysis.

The aim of this project is to determine the best daubechies wavelet and to differentiate the acoustic emission data before and after de-noising using One Dimensional (1-D) wavelet packet analysis. The objective of this project will be achieved through the planning from the beginning until the end of this project. The information about the case study is collect from many sources and mostly came from the journal and its gather together in the literature review section.

Best daubechies wavelet level is db3 for de-noising using 1-D wavelet packet analysis because the different value between before and after gives all positive (+ve) value. Compare with haar, daubechius and mexican hat wavelet, daubechius is the most suitable for wavelet analysis. *Bangi* number, α were used to show the different between smooth and rough pipe become more significant.

5.2 Suggestions

The result for the de-noising signal based on the type 3 @ db3 dauebchies from 1-D wavelet packet analysis and the signal were de-noised using different type of daubechies which is from type 1 until 12. For the future, maybe it can be done until daubechies type 24 to increase the accuracy of the result and it can compare with the previous result to see the differences and it can be improve the result before.

Besides that, there are a significant different between the Bangi number with the previous experiment and maybe in the future this experiment can be carried out to give a better result for de-noising signal using 1-D wavelet packet analysis.

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APPENDIX 1

List Of Command For Signal Analysis Using MATLAB

```
%Pipe analysis
%TIME DOMAIN ANALYSIS;
%t=starting time:time/(count-1): time/(count-1)*count;
%time=count/no samplepersec;

x1 = xc

t=0:0.0000002:0.000819;

%subplot(111),plot(t,x1)

X=[x1];
[m,n]=size(X);
for i=1:n
vrms1 (i,:)=sqrt(mean(X(:,i).^2));
vmax1 (i,:)=max(X(:,i));
vegy1 (i,:)=trapz(abs(X(:,i)));
vrms1 (i,:)=sqrt(mean(X(:,i).^2));
vmax1 (i,:)=max(X(:,i));
vegy1 (i,:)=trapz(abs(X(:,i)));


end
clear X;

 [vrms1 vmax1 vegy1]

vrmsavg1=mean(vrms1);
vmaxavg1=mean(vmax1);
vengavg1=mean(vegy1);

[vrmsavg1 vmaxavg1 vengavg1]
```

APPENDIX 2

Peak Amplitude Value (In Unit Volt) for db3 for Rough Pipe in High Flow Rate

Peak Amplitude at point (1)		
No.	Before	After (Level 3)
2	0.0043	0.0041
3	0.0043	0.0044
4	0.0092	0.0097
5	0.0034	0.0037
6	0.0018	0.0017
7	0.0058	0.0069
8	0.0034	0.0034
9	0.0073	0.0079
10	0.0031	0.0031
11	0.0037	0.0042
12	0.0034	0.0042
13	0.0037	0.004
14	0.0037	0.0036
15	0.0031	0.0034
16	0.0061	0.0063
17	0.004	0.0048
Average =	0.004394	0.0047125

Peak Amplitude at point (2)		
No.	Before	After
2	0.0037	0.0034
3	0.0037	0.0011
4	0.0089	0.0086
5	0.0348	0.0378
6	0.004	0.0046
7	0.004	0.0039
8	0.0043	0.0049
9	0.0031	0.0032
10	0.0037	0.0037
11	0.0027	0.0027
12	0.0046	0.0048
13	0.0064	0.0058
14	0.0043	0.0042
15	0.0037	0.0038
16	0.0076	0.0076
17	0.0064	0.0063
18	0.0027	0.0029
19	0.0055	0.0057
20	0.0034	0.0036
21	0.0076	0.0073
22	0.0037	0.0038
23	0.0055	0.0038
24	0.0034	0.0058
25	0.0055	0.0056
26	0.004	0.0041
27	0.0159	0.0166
28	0.0043	0.0042
29	0.0067	0.0072
30	0.0031	0.0032
Average =	0.00611	0.006213793

Peak Amplitude at point (3)			Peak Amplitude at point (4)		
No.	Before	After	No.	Before	After
2	0.0031	0.0033	2	0.0101	0.0111
3	0.0082	0.0088	3	0.004	0.003
4	0.0055	0.0057	4	0.0143	0.009
5	0.0058	0.0061	5	0.0085	0.008
6	0.0031	0.0032	6	0.0037	0.0037
7	0.0031	0.0031	7	0.004	0.004
8	0.0052	0.0047	8	0.0034	0.0034
9	0.0064	0.0075	9	0.0009	0.001
10	0.004	0.0041	10	0.0034	0.0035
11	0.0037	0.0037	11	0.0055	0.0055
12	0.0034	0.0037	12	0.0034	0.0034
13	0.004	0.0042	13	0.0037	0.004
14	0.0043	0.0045	14	0.004	0.0041
15	0.0073	0.0073	15	0.004	0.0038
16	0.0092	0.0087	16	0.0043	0.0045
17	0.0046	0.005	17	0.004	0.0043
18	0.0037	0.0041	18	0.0052	0.0051
19	0.0049	0.0051	19	0.0043	0.0042
20	0.0037	0.0034	20	0.0031	0.0033
21	0.0073	0.0074	21	0.0061	0.006
22	0.0037	0.0036	22	0.0034	0.0034
23	0.0034	0.0033	23	0.0037	0.0037
24	0.0034	0.0036	24	0.0067	0.0066
25	0.004	0.004	25	0.0104	0.011
26	0.0076	0.0081			
27	0.0064	0.0062			
28	0.0034	0.0034			
29	0.0031	0.0031			
30	0.0037	0.0035			
Average =	0.0048	0.004910345	Average =	0.005171	0.004983333

RMS Value (In Unit Volt) for db3 for Rough Pipe in High Flow Rate

RMS(1)		
No.	Before	After (Level 3)
2	0.0011	0.0011
3	0.0014	0.0014
4	0.0025	0.0025
5	0.0011	0.001
6	0.0005	0.0005
7	0.0014	0.0013
8	0.0008	0.0008
9	0.0018	0.0017
10	0.0008	0.0007
11	0.0008	0.0008
12	0.0007	0.0007
13	0.0008	0.0008
14	0.0008	0.0008
15	0.001	0.0009
16	0.0013	0.0012
17	0.0007	0.0006
Average =	0.001094	0.00105

RMS (2)		
No.	Before	After
2	0.001	0.0009
3	0.0003	0.0002
4	0.0029	0.0029
5	0.0072	0.0072
6	0.0012	0.0011
7	0.0011	0.0011
8	0.0011	0.0011
9	0.0007	0.0007
10	0.001	0.001
11	0.0008	0.0007
12	0.001	0.001
13	0.0017	0.0016
14	0.0009	0.0009
15	0.0008	0.0008
16	0.0017	0.0017
17	0.0018	0.0018
18	0.0007	0.0007
19	0.0015	0.0015
20	0.001	0.001
21	0.002	0.002
22	0.0009	0.0009
23	0.0017	0.0009
24	0.0008	0.0017
25	0.0015	0.0015
26	0.0011	0.0011
27	0.0046	0.0045
28	0.001	0.001
29	0.0016	0.0015
30	0.0008	0.0008
Average =	0.001531	0.001510345

RMS (3)		
No.	Before	After
2	0.0011	0.0011
3	0.0018	0.0018
4	0.0015	0.0015
5	0.0016	0.0016
6	0.0008	0.0007
7	0.0008	0.0008
8	0.0012	0.0011
9	0.0019	0.0019
10	0.0011	0.0011
11	0.0009	0.0009
12	0.0009	0.0009
13	0.0014	0.0014
14	0.0013	0.0013
15	0.0021	0.002
16	0.0023	0.0022
17	0.0017	0.0017
18	0.0011	0.001
19	0.0013	0.0013
20	0.0011	0.0011
21	0.0016	0.0016
22	0.0009	0.0009
23	0.0008	0.0008
24	0.0009	0.0009
25	0.0013	0.0012
26	0.0019	0.0019
27	0.0019	0.0019
28	0.001	0.001
29	0.0009	0.0009
30	0.001	0.001
Average =	0.001314	0.001293103

RMS (4)		
No.	Before	After
2	0.0026	0.0025
3	0.0008	0.0025
4	0.0029	0.0008
5	0.0019	0.0029
6	0.0009	0.0008
7	0.0011	0.0011
8	0.0009	0.0009
9	0.0003	0.0003
10	0.001	0.0009
11	0.0013	0.0013
12	0.0008	0.0008
13	0.0008	0.0008
14	0.0011	0.0011
15	0.001	0.001
16	0.0012	0.0012
17	0.0011	0.0011
18	0.0016	0.0016
19	0.0012	0.0011
20	0.0009	0.0009
21	0.0015	0.0015
22	0.0007	0.0007
23	0.0011	0.0011
24	0.0017	0.0017
25	0.0029	0.0029
Average =	0.001304	0.0013125

Energy Value (In Unit Joule) for db3 for Rough Pipe in High Flow Rate

ENERGY (1)		
No.	Before	After
2	3.1628	3.162
3	4.1945	4.1541
4	7.1606	7.0812
5	3.3493	3.3378
6	1.3562	1.3481
7	3.8036	3.6623
8	2.5436	2.5458
9	5.0253	4.8035
10	2.1986	1.98
11	2.5443	2.5032
12	2.0038	1.7917
13	2.0035	2.0059
14	2.2429	2.2205
15	2.8224	2.7754
16	3.2623	3.1392
17	1.8379	1.7177
Average =	3.094475	3.014275

ENERGY (2)		
No.	Before	After
2	2.744	2.74
3	0.607	0.5842
4	8.6795	8.6774
5	17.5	17.3447
6	3.4467	3.3747
7	2.9742	2.974
8	2.954	2.9324
9	1.8164	1.8066
10	2.8818	2.874
11	2.1112	2.0829
12	2.8104	2.8101
13	4.7789	4.7232
14	2.5957	2.59
15	2.2838	2.2787
16	4.3556	4.3445
17	5.1982	5.1603
18	1.9478	1.9425
19	4.27	4.267
20	2.8871	2.8855
21	5.5362	5.5158
22	2.1837	2.1815
23	5.0644	2.1915
24	2.2098	2.0368
25	4.4211	4.3907
26	2.997	2.9869
27	12.5237	12.4131
28	2.5334	2.5154
29	4.0454	3.9943
30	2.2594	2.2441
Average =	4.159186	4.029751724

ENERGY (3)		
No.	Before	After
2	3.5436	3.536
3	5.2681	5.2247
4	3.9746	3.9747
5	4.4692	4.4664
6	2.2473	2.2261
7	2.1825	2.1842
8	3.4489	3.4213
9	5.5374	5.4686
10	3.3254	3.3289
11	2.5586	2.5557
12	2.7461	2.7334
13	4.1794	4.1575
14	3.5988	3.5818
15	5.8893	5.8748
16	6.1754	6.1553
17	5.0305	5.0135
18	3.0338	3.0031
19	3.9493	3.9388
20	3.0537	3.0504
21	4.5323	4.5243
22	2.3636	2.3677
23	2.4802	2.4828
24	2.7118	2.7128
25	4.0842	4.0844
26	5.0684	5.0623
27	5.6042	5.591
28	3.1072	3.111
29	2.6395	2.6507
30	2.8256	2.8274
Average =	3.780307	3.769296552

ENERGY (4)		
No.	Before	After
2	7.0511	7.023
3	2.1549	2.1568
4	7.4561	7.423
5	5.032	5.022
6	2.5615	2.5658
7	3.1351	3.1327
8	2.7899	2.778
9	1.0005	1.0118
10	2.9298	2.9251
11	3.4946	3.4883
12	2.289	2.2865
13	2.3654	2.3719
14	3.3493	3.3506
15	3.1136	3.1121
16	3.3431	3.3419
17	3.2976	3.2922
18	4.9158	4.8785
19	3.717	3.6893
20	2.69	2.6852
21	4.0569	4.0571
22	2.1132	2.1259
23	3.0234	3.0266
24	4.9995	4.9417
25	8.2973	8.2854
Average =	3.715692	3.707141667

Peak Amplitude Value (In Unit Volt) for db3 for Rough Pipe in Low Flow Rate

Peak (1)		
No.	Before	After
2	0.0061	0.006
3	0.0055	0.0053
4	0.0043	0.0046
5	0.0058	0.0065
6	0.0034	0.0036
7	0.0027	0.0026
8	0.0043	0.0043
9	0.0055	0.0061
10	0.0046	0.0043
11	0.0058	0.0063
12	0.0259	0.0288
13	0.0034	0.0038
14	0.0031	0.0033
15	0.0101	0.0105
16	0.0037	0.004
17	0.0156	0.0169
18	0.0085	0.0089
19	0.0174	0.018
20	0.0037	0.0037
21	0.0046	0.0045
22	0.0043	0.0045
23	0.0034	0.0034
24	0.0049	0.0032
25	0.0098	0.0108
26	0.0085	0.0095
27	0.0027	0.0034
28	0.0052	0.0055
29	0.004	0.0036
30	0.0217	0.0187
Average =	0.0071897	0.0074

Peak (2)		
No.	Before	After
2	0.0031	0.003
3	0.0027	0.0028
4	0.0058	0.0028
5	0.0046	0.0052
6	0.0061	0.0065
7	0.0034	0.0033
8	0.0046	0.0052
9	0.0034	0.0031
10	0.0043	0.0048
11	0.0046	0.0041
12	0.0055	0.0058
13	0.0046	0.0046
14	0.0027	0.0029
15	0.0092	0.0099
16	0.0034	0.0035
17	0.0085	0.008
18	0.0101	0.0099
19	0.0043	0.0045
20	0.0031	0.0032
21	0.0079	0.0082
22	0.0027	0.0028
23	0.0037	0.0035
24	0.0055	0.0062
25	0.0034	0.0036
26	0.0064	0.0067
27	0.0037	0.004
28	0.0052	0.0064
29	0.0037	0.0041
30	0.0037	0.004
Average =	0.0048241	0.004917241

Peak (3)		
No.	Before	After
2	0.0055	0.0059
3	0.0055	0.0057
4	0.0067	0.0064
5	0.0125	0.0141
6	0.0082	0.008
7	0.004	0.0048
8	0.0043	0.0044
9	0.0049	0.0052
10	0.0116	0.0125
11	0.0043	0.0049
12	0.004	0.0045
13	0.011	0.0104
14	0.0027	0.0027
15	0.0037	0.0037
16	0.004	0.0041
17	0.0055	0.0054
18	0.0061	0.0068
19	0.0061	0.007
20	0.0037	0.0041
21	0.0046	0.0056
22	0.0034	0.0037
23	0.0043	0.0047
24	0.0031	0.0033
25	0.0064	0.0068
26	0.0085	0.0097
27	0.0027	0.0031
28	0.0049	0.0054
29	0.0098	0.0106
30	0.0031	0.0032
Average =	0.005693	0.006093103

Peak (4)		
No.	Before	After
2	0.0122	0.0128
3	0.0034	0.0035
4	0.004	0.004
5	0.0043	0.0046
6	0.0043	0.0042
7	0.0089	0.0089
8	0.0098	0.0113
9	0.004	0.004
10	0.0024	0.0026
11	0.0037	0.0041
12	0.0162	0.0166
13	0.0034	0.0031
14	0.0031	0.0031
15	0.0089	0.0103
16	0.0061	0.0069
17	0.0015	0.0017
18	0.0037	0.0036
19	0.0027	0.003
20	0.0034	0.0037
21	0.0049	0.0054
22	0.007	0.0077
23	0.004	0.0043
24	0.0055	0.0054
25	0.0009	0.0008
26	0.0046	0.0047
27	0.0034	0.0037
28	0.0046	0.005
29	0.007	0.0078
30	0.0027	0.0032
Average =	0.005193	0.005517241

RMS Value (In Unit Volt) for db3 for Rough Pipe in Low Flow Rate

RMS (1)		
No.	Before	After
2	0.0015	0.0015
3	0.0012	0.0012
4	0.001	0.001
5	0.0016	0.0016
6	0.0008	0.0008
7	0.0007	0.0007
8	0.001	0.001
9	0.0014	0.0013
10	0.0012	0.0012
11	0.0013	0.0013
12	0.0065	0.0063
13	0.0007	0.0007
14	0.0008	0.0008
15	0.0028	0.0028
16	0.0009	0.0009
17	0.0038	0.0038
18	0.0022	0.0021
19	0.0042	0.004
20	0.001	0.001
21	0.0011	0.0011
22	0.0011	0.0011
23	0.0008	0.0008
24	0.0004	0.0003
25	0.0028	0.0027
26	0.0024	0.0023
27	0.0007	0.0007
28	0.0011	0.0011
29	0.0008	0.0008
30	0.0048	0.0046
Average =	0.0017448	0.001706897

RMS (2)		
No.	Before	After
2	0.0008	0.00076
3	0.0008	0.0007
4	0.0016	0.0007
5	0.0011	0.001
6	0.0019	0.0019
7	0.001	0.001
8	0.0013	0.0013
9	0.0011	0.0011
10	0.001	0.0009
11	0.0013	0.0013
12	0.0015	0.0014
13	0.0013	0.0013
14	0.0009	0.0009
15	0.0024	0.0023
16	0.0008	0.0008
17	0.0021	0.0021
18	0.0022	0.0022
19	0.0015	0.0014
20	0.0009	0.0009
21	0.0018	0.0018
22	0.0008	0.0008
23	0.001	0.001
24	0.0017	0.0016
25	0.0009	0.0009
26	0.0019	0.0018
27	0.0008	0.0008
28	0.0015	0.0014
29	0.001	0.001
30	0.0009	0.0009
Average =	0.0013034	0.00124

RMS (3)		
No.	Before	After
2	0.0013	0.0012
3	0.0016	0.0016
4	0.002	0.002
5	0.0032	0.0031
6	0.002	0.002
7	0.001	0.001
8	0.0013	0.0013
9	0.0016	0.0016
10	0.0025	0.0024
11	0.0013	0.0013
12	0.0014	0.0013
13	0.0032	0.0032
14	0.0008	0.0008
15	0.0012	0.0011
16	0.0011	0.001
17	0.0014	0.0014
18	0.0016	0.0016
19	0.0015	0.0015
20	0.001	0.001
21	0.001	0.001
22	0.0009	0.0009
23	0.0012	0.0011
24	0.0009	0.0009
25	0.0018	0.0017
26	0.0022	0.0021
27	0.0009	0.0009
28	0.0013	0.0013
29	0.0023	0.0022
30	0.0009	0.0009
Average =	0.001531	0.001496552

RMS (4)		
No.	Before	After
2	0.0029	0.0029
3	0.0009	0.0009
4	0.0012	0.0012
5	0.0011	0.0011
6	0.001	0.001
7	0.0024	0.0024
8	0.0024	0.0023
9	0.0012	0.0012
10	0.0009	0.0009
11	0.0011	0.0011
12	0.0039	0.0039
13	0.0009	0.0009
14	0.0009	0.0009
15	0.0026	0.0025
16	0.0021	0.0021
17	0.0005	0.0005
18	0.0009	0.0008
19	0.0006	0.0006
20	0.0008	0.0008
21	0.0014	0.0014
22	0.0019	0.0019
23	0.0012	0.0012
24	0.0017	0.0017
25	0.0003	0.0003
26	0.0017	0.0016
27	0.0009	0.0009
28	0.0012	0.0011
29	0.0022	0.0021
30	0.0009	0.0008
Average =	0.001438	0.001413793

Energy Value (In Unit Joule) for db3 for Rough Pipe in Low Flow Rate

ENERGY (1)		
No.	Before	After (Level 3)
2	4.1243	4.0513
3	3.5007	3.4435
4	2.6105	2.5894
5	4.9857	4.8355
6	2.318	2.3134
7	2.1771	2.1625
8	2.7364	2.7131
9	3.8742	3.7174
10	3.5292	3.4967
11	3.4993	3.4511
12	17.0775	16.5917
13	2.0392	1.9859
14	2.4728	2.4484
15	8.0045	7.782
16	2.6268	2.5993
17	9.6109	9.4918
18	6.4488	6.3639
19	10.7159	10.0969
20	2.975	2.9205
21	2.9857	2.9552
22	3.1866	3.1616
23	2.4828	2.4703
24	0.8302	0.7912
25	8.0342	7.8158
26	6.7023	6.5384
27	2.1144	2.0289
28	2.9994	2.9743
29	2.1033	2.0998
30	12.6482	11.9278
Average =	4.8073759	4.683365517

ENERGY (2)		
No.	Before	After (Level 3)
2	2.3279	2.3276
3	2.2202	2.2007
4	4.9593	4.891
5	3.1607	3.1501
6	5.3455	5.2678
7	2.9269	2.9258
8	3.79	3.7674
9	3.3827	3.3531
10	2.6363	2.6116
11	3.8022	3.7838
12	4.055	4.0103
13	3.6887	3.6792
14	2.5766	2.5513
15	6.9582	6.8008
16	2.2757	2.2769
17	5.7567	5.6954
18	6.2016	6.159
19	4.1751	4.1416
20	2.426	2.4217
21	4.9287	4.8854
22	2.3492	2.3535
23	2.8825	2.8658
24	4.9237	4.6712
25	2.8073	2.7456
26	5.486	5.4401
27	2.4548	2.3837
28	4.4289	4.1162
29	2.924	2.8588
30	2.3985	2.3654
Average =	3.7327207	3.679337931

ENERGY (3)		
No.	Before	After (Level 3)
2	3.9029	3.7821
3	4.3849	4.3362
4	5.6891	5.6166
5	9.2052	8.8739
6	5.5277	5.4476
7	3.0707	2.9731
8	3.8261	3.8069
9	4.7461	4.7063
10	7.2325	7.0072
11	3.9127	3.8024
12	4.2577	4.1883
13	9.2168	9.0632
14	2.4126	2.3577
15	3.271	3.2553
16	2.9001	2.8959
17	4.3852	4.315
18	4.6158	4.4058
19	4.3689	4.2537
20	2.8348	2.7709
21	2.9897	2.9143
22	2.5208	2.5189
23	3.3247	3.2752
24	2.518	2.5013
25	5.3052	5.1238
26	6.3216	6.2223
27	2.5362	2.4841
28	4.1335	3.9478
29	6.0963	5.9442
30	2.6506	2.6509
Average =	4.419221	4.325548276

ENERGY (4)		
No.	Before	After (Level 3)
2	7.8301	7.5976
3	2.6582	2.6443
4	3.6491	3.6253
5	3.2762	3.2156
6	3.0576	2.9865
7	6.9484	6.7641
8	7.0549	6.8288
9	3.575	3.5565
10	2.9018	2.8816
11	3.3315	3.2743
12	11.2723	10.9917
13	2.6509	2.6276
14	2.6335	2.6058
15	7.4435	7.1703
16	6.2222	6.1265
17	1.4255	1.3983
18	2.5124	2.4561
19	1.7899	1.76
20	2.5581	2.541
21	4.2793	4.2106
22	6.0272	5.9215
23	3.932	3.8001
24	5.0612	4.9971
25	0.8513	0.8608
26	4.9936	4.8908
27	2.7733	2.7125
28	3.5675	3.4465
29	6.8375	6.6419
30	2.5813	2.5491
Average =	4.265355	4.175268966

Peak Amplitude Value (Volt) for db3 for Smooth Pipe in High Flow Rate

Peak (1)		
No.	Before	After
2	0.0061	0.0067
3	0.0052	0.0067
4	0.0049	0.0053
5	0.0064	0.0062
6	0.0107	0.0098
7	0.0037	0.0038
8	0.0067	0.0059
9	0.0037	0.0037
10	0.011	0.0109
11	0.0037	0.0038
12	0.0046	0.0054
13	0.0034	0.0045
14	0.0024	0.0024
15	0.0031	0.003
16	0.0034	0.0035
17	0.0031	0.0034
18	0.0055	0.0052
19	0.0092	0.0101
20	0.0061	0.007
21	0.0043	0.0046
22	0.0027	0.0032
23	0.0055	0.0057
24	0.0223	0.0287
25	0.004	0.0044
26	0.004	0.0043
27	0.0058	0.0064
28	0.0131	0.0118
29	0.0037	0.0033
30	0.0058	0.0056
Average =	0.00600344	0.006389655

Peak (2)		
No.	Before	After
2	0.004	0.0044
3	0.0079	0.008
4	0.0082	0.0073
5	0.0064	0.0067
6	0.0046	0.0051
7	0.0049	0.0048
8	0.0034	0.0039
9	0.0034	0.0038
10	0.0046	0.0045
11	0.004	0.0042
12	0.0058	0.0066
13	0.0031	0.0033
14	0.0034	0.0043
15	0.0034	0.0042
16	0.0311	0.0344
17	0.0031	0.0031
18	0.0043	0.0048
19	0.0146	0.0164
20	0.0049	0.005
21	0.0037	0.0038
22	0.0043	0.0043
23	0.0073	0.008
24	0.0043	0.005
25	0.0055	0.0054
26	0.0092	0.0097
27	0.0049	0.0051
28	0.0034	0.0034
29	0.0034	0.0037
30	0.0052	0.0053
Average =	0.006079	0.0065

Peak (3)		
No.	Before	After
2	0.0061	0.0066
3	0.0067	0.0065
4	0.0043	0.0045
5	0.0095	0.0105
6	0.0052	0.0047
7	0.004	0.0038
8	0.0079	0.0097
9	0.0031	0.0032
10	0.0073	0.0077
11	0.0031	0.0032
12	0.0046	0.0032
13	0.0034	0.0026
14	0.0058	0.006
15	0.0089	0.0095
16	0.0049	0.0046
17	0.0034	0.0036
18	0.004	0.0041
19	0.0034	0.0037
20	0.0034	0.0036
21	0.011	0.0111
22	0.004	0.0038
23	0.0058	0.0058
24	0.0052	0.0053
25	0.0034	0.0033
26	0.004	0.0041
27	0.0052	0.0052
28	0.0067	0.0068
29	0.0046	0.0047
30	0.0034	0.0034
Average =	0.005252	0.005337931

Peak (4)		
No.	Before	After
2	0.004	0.0037
3	0.0031	0.003
4	0.0043	0.0044
5	0.0049	0.0052
6	0.0043	0.004
7	0.0037	0.0036
8	0.0073	0.0071
9	0.0034	0.0035
10	0.0034	0.0036
11	0.0031	0.0033
12	0.0085	0.0093
13	0.0034	0.0033
14	0.0034	0.0036
15	0.007	0.008
16	0.004	0.0039
17	0.004	0.0035
18	0.0034	0.0033
19	0.0067	0.0066
20	0.0049	0.0046
21	0.0034	0.004
22	0.0058	0.0062
23	0.0046	0.0041
24	0.0073	0.0074
25	0.0049	0.0053
26	0.0073	0.0094
27	0.0085	0.0094
28	0.0034	0.0029
29	0.004	0.0039
30	0.0043	0.0046
Average =	0.004838	0.004989655

RMS Value (In Unit Volt) for db3 for Smooth Pipe in High Flow Rate

RMS (1)		
No.	Before	After
2	0.0014	0.0014
3	0.0013	0.0014
4	0.0014	0.0014
5	0.0015	0.0015
6	0.0021	0.002
7	0.0009	0.0009
8	0.0014	0.0014
9	0.0007	0.0006
10	0.0027	0.0026
11	0.0011	0.0011
12	0.0009	0.0008
13	0.0007	0.0006
14	0.0007	0.0006
15	0.0009	0.0009
16	0.001	0.0009
17	0.0009	0.0009
18	0.0012	0.0011
19	0.0023	0.0023
20	0.0013	0.0013
21	0.001	0.0009
22	0.0008	0.0008
23	0.0013	0.0012
24	0.0059	0.0054
25	0.0008	0.0007
26	0.0012	0.0011
27	0.0014	0.0014
28	0.0025	0.0024
29	0.0009	0.0008
30	0.0013	0.0012
Average =	0.001431034	0.001365517

RMS (2)		
No.	Before	After
2	0.0009	0.0009
3	0.0016	0.0016
4	0.0019	0.0018
5	0.0016	0.0016
6	0.0012	0.0012
7	0.001	0.001
8	0.0008	0.0008
9	0.001	0.001
10	0.0012	0.0012
11	0.0013	0.0013
12	0.0015	0.0015
13	0.0012	0.0011
14	0.0007	0.0007
15	0.0007	0.0006
16	0.0056	0.0054
17	0.0008	0.0008
18	0.0012	0.0011
19	0.0032	0.003
20	0.001	0.001
21	0.0011	0.0011
22	0.0008	0.0008
23	0.0013	0.0012
24	0.0014	0.0014
25	0.0016	0.0016
26	0.0017	0.0016
27	0.0013	0.0013
28	0.001	0.001
29	0.0008	0.0008
30	0.0012	0.0011
Average =	0.0014	0.001362069

RMS (3)		
No.	Before	After
2	0.0018	0.0018
3	0.0014	0.0014
4	0.001	0.001
5	0.0026	0.0025
6	0.0011	0.0011
7	0.0009	0.0009
8	0.0018	0.0018
9	0.0007	0.0007
10	0.0017	0.0016
11	0.0009	0.0009
12	0.0013	0.0009
13	0.0008	0.0007
14	0.0016	0.0016
15	0.002	0.0019
16	0.001	0.001
17	0.0009	0.0009
18	0.0009	0.0009
19	0.001	0.0009
20	0.0011	0.0011
21	0.0019	0.0018
22	0.0011	0.0011
23	0.0013	0.0013
24	0.0011	0.0011
25	0.0009	0.0009
26	0.0013	0.0012
27	0.0013	0.0013
28	0.0014	0.0013
29	0.0012	0.0012
30	0.0009	0.0009
Average =	0.001272	0.001231034

RMS (4)		
No.	Before	After
2	0.0008	0.0008
3	0.0008	0.0008
4	0.0013	0.0013
5	0.0011	0.0011
6	0.0012	0.0012
7	0.0009	0.0009
8	0.0019	0.0018
9	0.0008	0.0008
10	0.0009	0.0009
11	0.0009	0.0009
12	0.002	0.002
13	0.0008	0.0008
14	0.001	0.0009
15	0.0024	0.0024
16	0.0009	0.0009
17	0.0009	0.0009
18	0.0008	0.0008
19	0.0016	0.0016
20	0.0013	0.0012
21	0.0006	0.0006
22	0.0015	0.0015
23	0.001	0.0009
24	0.002	0.002
25	0.0016	0.0016
26	0.0015	0.0018
27	0.0018	0.0018
28	0.0008	0.0007
29	0.001	0.001
30	0.0009	0.0009
Average =	0.001207	0.0012

Energy Value (In Unit Joule) for db3 for Smooth Pipe in High Flow Rate

ENERGY (1)		
No.	Before	After (Level 3)
2	3.9478	3.8451
3	3.5967	3.8451
4	3.9978	3.9633
5	4.4629	4.229
6	5.4861	5.0931
7	2.4852	2.3737
8	4.0025	3.8715
9	1.8756	1.8451
10	6.9121	6.5715
11	3.0948	3.0477
12	2.431	2.3045
13	1.9659	1.8013
14	1.936	1.9118
15	2.8354	2.8008
16	2.717	2.6981
17	2.5662	2.5257
18	3.349	3.1454
19	6.5468	6.4106
20	3.8136	3.6883
21	2.9475	2.9214
22	2.5078	2.4363
23	3.6227	3.328
24	15.2676	13.9787
25	2.1614	2.0282
26	3.3719	3.2161
27	4.0767	3.9118
28	6.4282	6.2837
29	2.478	2.4743
30	3.4575	3.3409
Average =	3.942817241	3.789344828

ENERGY (2)		
No.	Before	After (Level 3)
2	2.5147	2.4618
3	4.2619	4.2592
4	5.2602	5.1295
5	4.1283	4.1068
6	3.3662	3.3304
7	2.8162	2.8137
8	2.4628	2.4348
9	3.075	3.0522
10	3.3814	3.3855
11	3.7613	3.7152
12	4.3126	4.1604
13	3.826	3.7921
14	1.9003	1.7973
15	1.9237	1.8072
16	14.4177	14.0691
17	2.341	2.341
18	3.4064	3.3243
19	8.5858	8.1852
20	2.8612	2.8255
21	3.1328	3.1158
22	2.3303	2.237
23	3.4537	3.3999
24	4.0224	3.9743
25	5.0565	4.9622
26	4.3889	4.3071
27	4.0616	3.9398
28	3.0284	3.0052
29	2.3319	2.3263
30	3.3572	3.2242
Average =	3.922979	3.844241379

ENERGY (3)		
No.	Before	After (Level 3)
2	5.204	5.1576
3	3.9467	3.9345
4	2.6584	2.6619
5	6.9826	6.7165
6	3.1189	3.0827
7	2.5696	2.5548
8	5.1663	5.0099
9	1.9652	1.9625
10	4.9275	4.7719
11	2.6102	2.6072
12	3.9587	2.6072
13	2.2412	2.1692
14	4.8463	4.8235
15	5.1813	4.9088
16	2.8737	2.7881
17	2.5533	2.5539
18	2.6582	2.6389
19	2.7565	2.7362
20	3.3603	3.3389
21	5.1678	4.9262
22	3.2715	3.251
23	3.8057	3.8015
24	2.9086	2.9079
25	2.601	2.6068
26	3.714	3.6484
27	3.7814	3.7432
28	3.6769	3.6769
29	3.5519	3.5156
30	2.8096	2.8171
Average =	3.616114	3.514441379

ENERGY (4)		
No.	Before	After (Level 3)
2	2.4504	2.4492
3	2.281	2.2711
4	3.6748	3.6792
5	3.2178	3.2019
6	3.4822	3.4737
7	2.7779	2.7762
8	5.1764	4.9589
9	2.3657	2.3625
10	2.6009	2.5769
11	2.8299	2.797
12	5.713	5.5842
13	2.4521	2.453
14	2.9297	2.8035
15	7.0627	6.999
16	2.5201	2.4528
17	2.7364	2.6834
18	2.3795	2.3863
19	4.4539	4.3737
20	3.7143	3.6706
21	1.7766	1.6927
22	4.2236	4.2023
23	2.6656	2.5879
24	5.648	5.6037
25	4.9393	4.9191
26	4.3852	4.72
27	4.9243	4.72
28	2.2777	2.1514
29	2.8967	2.8912
30	2.6756	2.6735
Average =	3.490734	3.452237931

Peak Amplitude Value (In Unit Volt) for db3 for Smooth Pipe in Low Flow Rate

Peak (1)		
No.	Before	After
2	0.0031	0.0033
3	0.0027	0.0028
4	0.0061	0.0072
5	0.0104	0.01
6	0.0055	0.0053
7	0.0037	0.004
8	0.004	0.0041
9	0.0034	0.0041
10	0.0055	0.0058
11	0.0076	0.0075
12	0.014	0.0147
13	0.0058	0.0056
14	0.0089	0.0085
15	0.0052	0.0055
16	0.0049	0.0042
17	0.0073	0.0085
18	0.0052	0.0056
19	0.0092	0.011
20	0.0079	0.0097
21	0.0061	0.0075
22	0.0064	0.008
23	0.0049	0.0057
24	0.004	0.0043
25	0.0061	0.0059
26	0.0037	0.0033
27	0.0055	0.0061
28	0.0027	0.0032
29	0.0043	0.0043
30	0.0037	0.0027
Average =	0.005786207	0.006151724

Peak (2)		
No.	Before	After
2	0.0037	0.0046
3	0.0049	0.0057
4	0.0079	0.0081
5	0.0043	0.0047
6	0.004	0.0046
7	0.0027	0.0027
8	0.011	0.0125
9	0.0037	0.0046
10	0.0058	0.0065
11	0.004	0.0044
12	0.0134	0.0129
13	0.0125	0.0134
14	0.0052	0.0056
15	0.0058	0.006
16	0.0049	0.0057
17	0.0034	0.0045
18	0.0317	0.033
19	0.014	0.0136
20	0.0037	0.0034
21	0.0156	0.0154
22	0.0067	0.0072
23	0.0034	0.0036
24	0.0052	0.0051
25	0.0134	0.0124
26	0.0031	0.0035
27	0.0055	0.0054
28	0.0168	0.0157
29	0.0104	0.0111
30	0.0125	0.0132
Average =	0.008248	0.008589655

Peak (3)		
No.	Before	After
2	0.0125	0.014
3	0.0195	0.0189
4	0.0076	0.0088
5	0.0037	0.0037
6	0.007	0.0059
7	0.0131	0.0136
8	0.0058	0.0058
9	0.0186	0.0209
10	0.0092	0.0087
11	0.0043	0.0045
12	0.007	0.0069
13	0.0082	0.008
14	0.007	0.0076
15	0.0174	0.02
16	0.0092	0.0083
17	0.0049	0.0054
18	0.004	0.0046
19	0.0055	0.0061
20	0.007	0.0078
21	0.0043	0.0044
22	0.0046	0.0049
23	0.0046	0.0037
24	0.0076	0.0069
25	0.0153	0.014
26	0.0076	0.008
27	0.0043	0.0052
28	0.0079	0.0084
29	0.0076	0.0086
30	0.0043	0.0042
Average =	0.008262	0.008544828

Peak (4)		
No.	Before	After
2	0.0085	0.0084
3	0.011	0.0118
4	0.0061	0.0065
5	0.0113	0.0121
6	0.0055	0.0059
7	0.0089	0.0078
8	0.0079	0.01
9	0.0037	0.0039
10	0.0046	0.0048
11	0.0128	0.0127
12	0.0034	0.0034
13	0.0034	0.0034
14	0.0122	0.0131
15	0.004	0.0041
16	0.0076	0.0082
17	0.0067	0.0068
18	0.0119	0.0148
19	0.0128	0.0108
20	0.0061	0.0057
21	0.0229	0.0243
22	0.0101	0.0106
23	0.0134	0.0159
24	0.004	0.0041
25	0.0082	0.0091
26	0.0061	0.0064
27	0.015	0.0145
28	0.0034	0.0038
29	0.0046	0.0043
30	0.0046	0.0047
Average =	0.0083	0.008686207

RMS Value (In Unit Volt) for db3 for Smooth Pipe in Low Flow Rate

RMS (1)		
No.	Before	After
2	0.0011	0.001
3	0.0009	0.0008
4	0.0012	0.0012
5	0.0022	0.0021
6	0.0014	0.0013
7	0.0011	0.0011
8	0.001	0.001
9	0.0008	0.0008
10	0.0017	0.0016
11	0.0023	0.0022
12	0.0041	0.0038
13	0.0015	0.0015
14	0.0021	0.002
15	0.0015	0.0014
16	0.0004	0.0004
17	0.0022	0.0022
18	0.0013	0.0013
19	0.002	0.0018
20	0.0018	0.0017
21	0.0017	0.0017
22	0.0014	0.0014
23	0.001	0.0009
24	0.001	0.0009
25	0.0015	0.0015
26	0.0009	0.0008
27	0.0017	0.0017
28	0.0008	0.0008
29	0.0013	0.0013
30	0.0004	0.0003
Average =	0.001458621	0.001396552

RMS (2)		
No.	Before	After
2	0.001	0.001
3	0.0013	0.0012
4	0.0018	0.0017
5	0.001	0.001
6	0.0012	0.0011
7	0.0009	0.0009
8	0.0031	0.003
9	0.0009	0.0009
10	0.0016	0.0015
11	0.0011	0.001
12	0.0035	0.0033
13	0.0028	0.0028
14	0.0014	0.0014
15	0.0014	0.0013
16	0.0013	0.0012
17	0.0009	0.0008
18	0.0068	0.0065
19	0.0042	0.0041
20	0.001	0.001
21	0.0037	0.0036
22	0.0015	0.0015
23	0.0009	0.0008
24	0.0012	0.0011
25	0.0036	0.0036
26	0.0011	0.001
27	0.0014	0.0013
28	0.0044	0.0043
29	0.0027	0.0026
30	0.0028	0.0027
Average =	0.002086	0.002006897

RMS (3)		
No.	Before	After
2	0.0032	0.003
3	0.0044	0.0041
4	0.0019	0.0018
5	0.001	0.001
6	0.0018	0.0017
7	0.003	0.0029
8	0.0015	0.0015
9	0.0051	0.0049
10	0.0026	0.0026
11	0.001	0.001
12	0.0019	0.0019
13	0.0022	0.0022
14	0.0021	0.0019
15	0.0061	0.0059
16	0.0023	0.0022
17	0.0014	0.0013
18	0.0011	0.0011
19	0.0017	0.0016
20	0.002	0.002
21	0.0014	0.0014
22	0.001	0.001
23	0.0011	0.001
24	0.0018	0.0018
25	0.0032	0.0031
26	0.0023	0.0023
27	0.0011	0.001
28	0.0021	0.0021
29	0.0017	0.0016
30	0.001	0.001
Average =	0.002172	0.0021

RMS (4)		
No.	Before	After
2	0.0021	0.0021
3	0.0026	0.0026
4	0.0021	0.002
5	0.0028	0.0027
6	0.0016	0.0016
7	0.0021	0.002
8	0.0018	0.0017
9	0.0011	0.001
10	0.0012	0.0012
11	0.0028	0.0027
12	0.001	0.001
13	0.0006	0.0006
14	0.0032	0.0031
15	0.0009	0.0008
16	0.0017	0.0017
17	0.0017	0.0016
18	0.0032	0.0031
19	0.0032	0.0031
20	0.0015	0.0014
21	0.0046	0.0045
22	0.0034	0.0032
23	0.0024	0.0022
24	0.0011	0.0011
25	0.0021	0.002
26	0.0015	0.0015
27	0.0028	0.0027
28	0.0011	0.001
29	0.0011	0.0011
30	0.0014	0.0013
Average =	0.002024	0.001951724

Energy Value (In Unit Joule) for db3 for Smooth Pipe in Low Flow Rate

ENERGY (1)		
No.	Before	After (Level 3)
2	3.3427	3.2719
3	2.5682	2.4974
4	3.4348	3.2898
5	6.154	5.6648
6	4.0031	3.8985
7	3.5078	3.2728
8	3.0708	3.0176
9	2.3088	2.2039
10	5.4099	5.2548
11	6.7999	6.5817
12	11.7101	10.8066
13	4.6259	4.5198
14	6.0652	5.7021
15	4.5096	4.3273
16	0.8923	0.8395
17	6.6968	6.4161
18	4.203	4.1395
19	5.1712	4.7022
20	4.81	4.5578
21	4.9973	4.7597
22	3.8806	3.721
23	2.6729	2.5654
24	2.9118	2.8351
25	4.5274	4.4707
26	2.5496	2.4516
27	5.0462	4.9005
28	2.4373	2.3497
29	3.9049	3.8137
30	0.9074	0.8681
Average =	4.2455	4.058606897

ENERGY (2)		
No.	Before	After (Level 3)
2	3.0289	2.9193
3	3.8615	3.667
4	5.5122	5.2542
5	2.916	2.8278
6	3.6072	3.447
7	2.8093	2.785
8	8.9363	8.7627
9	2.8917	2.7657
10	4.5592	4.3528
11	3.1461	3.0514
12	9.6184	9.1996
13	8.2346	8.0702
14	3.9613	3.8786
15	4.0399	3.9207
16	3.7108	3.5755
17	2.5934	2.4886
18	16.9988	15.994
19	13.8274	13.4291
20	3.0988	2.9598
21	9.5856	9.3518
22	4.0196	3.9596
23	2.5873	2.486
24	3.4061	3.3244
25	9.6759	9.3168
26	3.4274	3.3153
27	4.1931	4.0726
28	12.0587	11.7449
29	7.7014	7.3404
30	7.4207	7.2017
Average =	5.911297	5.705603448

ENERGY (3)		
No.	Before	After (Level 3)
2	8.8234	8.261
3	11.6315	10.8279
4	5.3066	5.0169
5	3.1335	3.0366
6	5.0943	4.9945
7	7.9619	7.6134
8	4.5586	4.4128
9	16.7473	15.7163
10	7.657	7.5373
11	2.9593	2.8045
12	6.1444	5.8252
13	6.1684	6.1101
14	6.3245	5.7914
15	19.9164	18.941
16	6.5688	6.2667
17	3.9853	3.7963
18	3.6647	3.535
19	4.7937	4.7083
20	5.5565	5.323
21	4.2999	4.1478
22	3.0734	2.9728
23	3.1613	2.9935
24	5.2673	5.1669
25	8.5529	8.3576
26	6.9066	6.7356
27	3.3772	3.203
28	6.1995	6.0585
29	5.0227	4.603
30	2.8346	2.7935
Average =	6.403155	6.122427586

ENERGY (4)		
No.	Before	After (Level 3)
2	6.1293	5.8878
3	7.2118	7.0262
4	6.1311	5.7703
5	7.9816	7.636
6	4.7759	4.6849
7	6.2759	5.9756
8	5.1868	4.8089
9	3.205	3.162
10	3.2729	3.2006
11	8.1192	7.6868
12	3.0051	2.945
13	1.7967	1.7329
14	8.8925	8.4972
15	2.6671	2.5188
16	5.2261	4.9541
17	4.9049	4.7063
18	9.1838	8.643
19	9.0944	8.6187
20	4.18	4.063
21	13.331	13.0039
22	11.1426	10.468
23	6.5179	5.9889
24	3.5419	3.4436
25	5.8145	5.6583
26	4.3997	4.2147
27	7.3701	7.0254
28	3.4319	3.3388
29	3.17	3.1051
30	4.0642	3.9583
Average =	5.862893	5.611141379